This report has been modified, but the changes are not reflected in the report below.

To view the EPA approved modification document, please return to the approved reports page located at https://www.deq.virginia.gov/TMDLDataSearch/ReportSearch.jspx and enter your query. In the results table, select "MODIFICATION" in the Final Reports column.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

SEP 02 1999

Mr. Larry G. Lawson, P.E.
Director, Division of Water Coordination
Department of Environmental Quality
P.O. Box 10009
Richmond, VA 23240

Re: Muddy Creek, Rockingham County
TMDL for Fecal Coliform

Dear Mr. Lawson:

The Environmental Protection Agency (EPA) Region III, is pleased to approve the Muddy Creek Watershed TMDL, originally sent to EPA by letter dated April 30, 1999, with revised reports dated May 24, 1999 and July 29, 1999. The latter revised report was modified in response to EPA's comments which were e-mailed on June 29, 1999. This TMDL was established and submitted in accordance with Section 303(d)(1)(c) and (2) of the Clean Water Act. The TMDL was established to address impairment of water quality as identified in Virginia's 1996 and 1998 Section 303(d) lists. Virginia identified the impairments for this water quality-limited segment of the Muddy Creek Watershed based on exceedances of the fecal coliform bacteria water quality standard.

In accordance with Federal regulations at 40 CFR § 130.7, a TMDL must be designed to meet water quality standards, and (1) include, as appropriate, both wasteload allocations (from point sources) and load allocations (from nonpoint sources), (2) consider the impacts of background pollutant contributions, (3) take critical stream conditions into account (the conditions when water quality is most likely to be violated), (4) consider seasonal variations, (5) include a margin of safety (which accounts for any uncertainties in the relationship between pollutant loads and instream water quality), and (6) be subject to public participation. The enclosure to this letter describes how the Muddy Creek Watershed TMDL satisfies each of these requirements.

Following the approval of this TMDL, Virginia shall incorporate the TMDL into the Water Quality Management Plan pursuant to 40 CFR § 130.7(d)(2). As you know, any new or revised National Pollution Discharge Elimination Systems (NPDES) must be consistent with the TMDL's

Waste Load Allocation (WLA) pursuant to 40 CFR § 122.44(d)(1)(vii)(B). Please submit all such permits to EPA for review consistent with EPA's letter dated October 1, 1998. If you have further questions, please call me or have your staff contact Mr. Thomas Henry, the TMDL Program Manager at 215-814-5752.

Sincerely,

James J. Burke
for

Thomas J. Maslany, Director
Water Protection Division

Enclosure

cc: Jack E. Frye, VDCR

DECISION RATIONAL DOCUMENT
TOTAL MAXIMUM DAILY LOAD (TMDL)
MUDDY CREEK, VIRGINIA
September 1, 1999

I. Introduction

This document sets forth the Environmental Protection Agency's (EPA) rationale for approving the Total Maximum Daily Load (TMDL) for fecal coliform bacteria for a portion of Muddy Creek. This TMDL was developed by the Virginia Department of Environmental Quality (DEQ), in cooperation with the Virginia Department of Conservation and Recreation. The revised *Final Report, Fecal Coliform TMDL Development for Muddy Creek, Virginia,* dated July 1999, sent July 29, 1999, and received by EPA on August 2, 1999. The revised report is a version of a report originally submitted April 30, 1999, which was modified to address EPA's concerns. EPA has determined that, based on information provided[1], the TMDL meets the following eight regulatory conditions as set forth in 40 CFR § 130:

1. The TMDL is designed to implement applicable water quality standards.
2. The TMDL includes a total allowable load as well as individual waste load allocations and load allocations.
3. The TMDL considers the impacts of background pollutant contributions.
4. The TMDL considers critical environmental conditions.
5. The TMDL considers seasonal environmental variations.
6. The TMDL includes a margin of safety.
7. The TMDL has been subject to public participation.
8. There is reasonable assurance that the TMDL can be achieved.

In acknowledgment of the need for Federal consistency, EPA provided a copy of the TMDL Report submitted to EPA on May 24, 1999, to the U.S. Fish and Wildlife Service (FWS) for review in consideration of potential impacts to endangered species in the vicinity of Muddy Creek. The June 28, 1999, FWS letter stated, "Based on review of the TMDL development package and the Muddy Creek watershed location, it appears that no impacts to federal listed or proposed species or critical habitat will occur." FWS offered two comments regarding the TMDL, one concerning Virginia's fecal standard and the other noting FWS's Partners for Fish and Wildlife Program which offers riparian habitat restoration services for private landowners.

II. Background

The Muddy Creek watershed is located in Rockingham County, Virginia, approximately 10 miles west of Harrisonburg, Virginia. Muddy Creek flows generally north to south, draining a 20,025 acre watershed which is part of the South Fork Shenandoah River basin (Hydrologic Unit 02070005) and is identified in Virginia's waterbody coding system as VAV-B22R. The eastern and central portions of the watershed are dominated by agricultural land uses, primarily poultry and dairy production, while the western-most portion is generally forested. Elevated

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[1] EPA considered some supporting information which may be included in the submittal, and in the public docket, but not the TMDL Final Report, in determining its approval.

levels of fecal coliform bacteria in Muddy Creek have been attributed largely to long-term, intensive, agricultural activity and can be traced to both direct discharges and storm water-related (nonpoint source) sources.

Clean Water Act (CWA) Section 303(d) and its implementing regulations require a TMDL to be developed for those water bodies identified as impaired by the State where technology-based and other required controls do not provide for attainment of water quality standards. In its 1998 Section 303(d) list of water quality-limited waters, Virginia DEQ identified Muddy Creek as failing to attain its designated uses as a result of multiple exceedences of the Commonwealth's water quality standard for fecal coliforms and for violations of Virginia's General Biological Standard. This 10.36-mile impaired stream segment begins at the headwaters of Muddy Creek and extends to its confluence with Dry River. A separate 7.04-mile segment of Muddy Creek, together with segments of Dry River and North River, was also identified on Virginia's 1998 Section 303(d) list as being use-impaired based on exceedences of Virginia's drinking water standard for nitrate-nitrogen of 10 mg/l. Virginia is in the process of developing a TMDL for nitrate-nitrogen for that water quality-limited segment.

Virginia developed the fecal coliform TMDL to achieve full compliance with the Commonwealth's water quality standard for fecal coliforms[2]. Table 1 below summarizes the elements of the TMDL.

Table 1. Summary of Fecal Coliform TMDL- Calculated To Average Annual Loading (Counts/Year)

Parameter	$TMDL_{200}$ [a]	WLA	LA	MOS
Fecal Coliforms	9.11×10^{12} [b]	3.04×10^{11} [c]	8.35×10^{12} [d]	4.56×10^{11} [e]

[a] $TMDL_{200}$ represents loading that would correspond to compliance with the 200 count/100ml geometric mean criterion. The MOS, then, is represented as (0.05 $TMDL_{200}$) and affects an approximation of the actual MOS, which was not directly addressed in the loading model.
[b] $TMDL = \sum WLA + \sum LA + MOS$
[c] Derived from Table 5.1 "Wasteload Allocations to Point Sources in the Muddy Creek Watershed" from Virginia's *Fecal Coliform TMDL Development for Muddy Creek, Virginia* (July 1999). Daily loadings were multiplied by 365 days.
[d] Summation of Total annual loads in Tables 5.2 and 5.3 (addressing land-use based on direct nonpoint source loadings in Muddy Creek) from *Fecal Coliform TMDL Development for Muddy Creek, Virginia* (July 1999).
[e] Virginia established a 5% MOS by targeting load reductions to meet a monthly geometric mean of 190 counts/100ml, rather than 200 counts/100ml of fecal coliform. In order to express this MOS explicitly for the purpose of this summary, the loading in Table 1 is calculated based on the equation $TMDL_{200} = WLA + LA + (0.05\ TMDL_{200})$.

Although Muddy Creek was originally placed on Virginia's 1998 303(d) list on the basis of violations of Virginia's instantaneous criterion for fecal coliforms (1000#/100ml), it is

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[2] Refer to Virginia Code 9 VAC 25-260-170. Also see further discussion, Section III.1.

important to note that Virginia's water quality standard has two situation-specific criteria. Virginia believes that the geometric mean criterion set forth in Virginia's fecal coliform water quality standard (200#/100ml) is the applicable criterion for TMDLs supported by continuous modeling (see section III.1 for more discussion). Therefore, in designing this TMDL to achieve Muddy Creek's full compliance with the water quality standard, Virginia has developed loading models which address the geometric mean criterion. This geometric mean criterion is intended to be evaluated based on a 30-day (or monthly, for practical purposes) assessment period. Virginia has chosen, however, to present overall load allocations for Muddy Creek on the basis of average annual loading. This decision is based on the fact that, due to significant variations in monthly (and daily, for that matter) average flow rates in the watershed, monthly maximum load calculations would not be directly comparable to one another, nor would averaging of these monthly parameters be appropriate. This approach is discussed in greater detail in section III.

III. Discussion of Regulatory Requirements

EPA finds that the TMDL calculated for fecal coliforms in Muddy Creek meets the regulatory requirements of the Clean Water Act. EPA's approval is outlined according to the regulatory requirements listed below.

1. The TMDL is designed to implement the applicable water quality standards

All Virginia waters, including Muddy Creek, are designated for recreational uses (*e.g.* swimming and boating); propagation and growth of wildlife, including game fish, which might reasonably be expected to inhabit them; wildlife habitat; and the production of edible and marketable natural resources (e.g. fish and shellfish)[3]. Muddy Creek is use-impaired for recreational purposes, based on the fecal coliform colony counts recorded by Virginia's ambient monitoring program.

In order to evaluate the maintenance of the recreational use element of these designated uses, Virginia has adopted a two-part, situation-specific, water quality standard for fecal coliforms. The standard requires the use of either an instantaneous maximum criterion (1000#/100ml) if only one sample is available for a 30-day period; or a geometric mean criterion (200#/100ml), in the event that more than one sample is available for a 30-day period. Because of resource constraints, Virginia's ambient monitoring program is generally designed to produce single samples representative of waters in the Commonwealth on a monthly basis. Consequently, Muddy Creek was placed on Virginia's 1998 Section 303(d) list on the basis of significant violations of Virginia's instantaneous criterion (1000#/100ml) in the Commonwealth's water quality standard.

Virginia believes, however, that, in circumstances where a TMDL is developed for an impaired water body using a continuous modeling methodology, and where adequate data to allow for proper calibration of the model is available, the geometric mean criterion (200#/100ml) is more appropriate to determine compliance with its water quality standard for fecal coliforms.

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[3] See 9VAC 23-260-10.

This reasoning is based on several factors: (1) additional field-data points are likely to be generated during TMDL development, (2) continuous modeling provides more than one evaluation opportunity for any given 30-day period, and (3) additional field-level sampling, capable of supporting geometric mean evaluations, is planned to verify implementation of the TMDL. Virginia has chosen, therefore, to develop wasteload and load allocations for this TMDL based on compliance with the geometric mean criterion contained in the Commonwealth's water quality standard. In achieving compliance with this criterion, the TMDL will implement the applicable water quality standard.

In order to best accommodate the application of fecal coliform loading calculations toward an evaluation of Virginia's concentration-based water quality standard for fecal coliform bacteria, the Muddy Creek TMDL has been expressed as a Total Maximum Annual Loading. The justification for this approach is discussed below. Extensive modeling was performed to ensure that the selected loading allocations for land uses and direct sources in the Muddy Creek watershed will correspond to 100% compliance with Virginia's concentration-based geometric mean water quality criterion for fecal coliforms, and Virginia has agreed to initiate a special monitoring program in order to properly evaluate Muddy Creek's future compliance with the geometric mean criterion.

2. The TMDL includes a total allowable load as well as individual waste load allocations and load allocations

Virginia calculated a total maximum allowable load of 9.11×10^{12} fecal coliforms per year from all sources in the Muddy Creek watershed, based on 100% compliance with Virginia's geometric mean water quality standard and the application of a 5% margin of safety (discussed in Section III.6.). The US EPA's BASINS Nonpoint Source Model was selected as the modeling framework to simulate existing hydrologic conditions, existing loadings, and target load allocations. In order to facilitate a more precise understanding of hydrologic processes and governing loading factors, the Muddy Creek watershed was divided into eight sub-watersheds. All land-use related and direct nonpoint sources (Tables 3 and 4) were evaluated for each of the sub-watersheds.

A. Wasteload Allocations

Virginia identified two permitted point sources in the Muddy Creek watershed. One of these permittees, the Mount Clinton school, has never had a recorded discharge and is scheduled for closure in the near future. While the school was determined not to be a significant point source, storm water-related run-off from the facility is addressed in the land-use nonpoint source (NPS) load allocation for the sub-watershed. The second permitted source, Wampler Foods, was determined to be contributing fecal loading at a rate several orders of magnitude below that of most nonpoint sources in the watershed, based on permit conditions. Nevertheless, a WLA was calculated for this single point source, based on available monitoring data and the maximum observed average monthly flow rate. Of the five permitted outfalls identified at the Wampler facility, two are designed as discharge points for collected storm water and are therefore addressed in the development of the land-use NPS load allocation for this sub-watershed. The remaining three permitted outfalls all flow to one discharge point; therefore average monthly flows and fecal coliform concentrations were aggregated to calculate the facility's WLA.

Table 2. Fecal Coliform Waste Load Allocation, Calculated on a Daily Basis[a].

Point Source	Sub-Watershed	Existing Load	WLA	% Reduction
Mt. Clinton School	Muddy 2	N/A	N/A	0
Wampler Foods, Inc.	Muddy 2	8.34×10^8	8.34×10^8	0

[a]Derived from Table 5.1 "Wasteload Allocations to Point Sources in the Muddy Creek Watershed" from Virginia's *Final Report, Fecal Coliform TMDL Development for Muddy Creek, Virginia* (July 1999).

B. Load Allocations.

Information on deer populations, numbers of cattle and other livestock, and livestock and manure management practices in the Muddy Creek watershed was used to calculate fecal coliform loadings from land-use based, nonpoint sources in each sub-watershed. Total fecal production rates were based on the number of animals present. On-land build-up rates resulting from agronomic application of manure and from direct deposition from grazing livestock were calculated on a monthly basis for each land-use category by sub-watershed. Additionally, "direct" nonpoint sources, such as failing septic systems, uncontrolled and illegal "straight pipes", and time spent by cattle in the stream were represented by discrete loadings. Virginia utilized standard book values and limited sensitivity analysis to arrive at satisfactory estimates for loadings from failing septic systems and other uncontrolled discharges. Virginia Department of Conservation and Recreation (DCR) aided in developing a specific procedure for calculating cattle access to streams in order to estimate the direct loading contribution of cattle in the stream itself. Finally, the calculated build-up rates and "direct" agricultural loadings were also compared with the projected total fecal coliform production rates, using a mass-balance approach, to ensure consistency.

Using the BASINS modeling framework, the following existing annual loads (Tables 3, 4 and 5) were determined, based on the selected five-year modeling period. The existing loads represent the present condition of the watershed. The in-stream fecal coliform concentrations associated with these loading rates corresponded well with Virginia's ambient monitoring program water quality data.

Table 3: Summary of NPS Fecal Coliform Loads By Land Use in Muddy Creek Watershed.

Land Use Category	Fecal Coliforms (average counts/yr)		
	Existing Load[a]	TMDL Load Allocation	% Reduction from current load
Built-Up	1.88×10^{10}	1.88×10^{10}	0

Land Use Category	Fecal Coliforms (average counts/yr)		
	Existing Load[a]	TMDL Load Allocation	% Reduction from current load
Farmstead	1.78×10^{10}	1.78×10^{10}	0
Forest	7.33×10^{10}	7.33×10^{10}	0
Barren	1.32×10^{8}	1.32×10^{8}	0
Cropland	2.48×10^{11}	2.16×10^{11}	13.1
Loafing Lots	4.11×10^{12}	8.08×10^{11}	80.3
Pasture 1[d]	1.72×10^{12}	1.01×10^{12}	41.3
Pasture 2	2.19×10^{11}	1.28×10^{11}	41.8
Pasture 3	3.34×10^{12}	1.94×10^{12}	42.0
Total	6.74×10^{14}	8.35×10^{12}	98.8

[a]The current load is the summation of build-up values multiplied by total acreage for each of 8 sub-watersheds.

[b]Pasture lands were divided into 3 categories, based on manure management practices and grazing intensity. Full explanation of the categorization can be found in Appendix A of Virginia's TMDL report.

Table 4: Summary of "Direct" NPS Fecal Coliform Loads in Muddy Creek Watershed.

Source Category	Fecal Coliforms (average counts/yr)		
	Existing Load	TMDL Load Allocation	% Reduction from current load
In-stream Cattle	5.82×10^{14}	4.14×10^{12}	99.3
Failing Septic Systems	7.72×10^{11}	0	100
Uncontrolled Discharges	8.12×10^{13}	0	100
Total	6.64×10^{14}	4.14×10^{12}	99.4

Table 5: **Summary of Combined Load Allocations for Fecal Coliforms in Muddy Creek**

NPS Source Type	Fecal Coliforms (counts/year)		
	Existing Load[a]	TMDL Load Allocation[c]	% reduction from existing load
Land-Use	9.75×10^{12}	4.21×10^{12}	56.8
Direct	6.64×10^{14}	4.14×10^{12}	99.4
Total	6.74×10^{14}	8.35×10^{12}	98.8

[a]The existing load is based on loads calculated for each of eight subwatersheds.

Examination of Tables 3 through 5 reveals that calculated loadings from "direct" nonpoint sources ranged 2-3 orders of magnitude higher than land-use related loadings. In developing TMDL load allocations for the nonpoint sources, Virginia opted to depend heavily on reducing the contributions of these sources because of the availability of proven and readily available management practices to reduce transport of fecal coliforms to Muddy Creek. For instance, Virginia selected a 99.3% reduction target for fecals loading from cattle actually loafing in the stream itself. This was judged to be desirable based on the assumption that near-complete stream fencing would remove all cattle from the stream, with the exception of specific areas designated as cattle crossings. Similarly, as to contributions from septic systems and straight pipes, Virginia has in place regulations requirement for the discharges to be eliminated. In particular, Virginia's Department of Health regulations state that "(t)he discharge of untreated sewage onto the land or into the waters of the Commonwealth is prohibited"[4]. Thus, a 100% reduction target for these source was deemed desirable.

Load allocations to the remaining land-use oriented nonpoint sources resulted in an overall 56.8% load reduction. Because of the high potential for fecal coliform loading from un-managed loafing lots, additional reductions from these sources substantially decrease the necessary reductions from other land-use sources. Since cost-effective management practices and support programs are readily available to address loafing lot loadings, a higher rate of load reduction will be sought for this category. Allocations for cropland and pasture lands were based on assessments of existing and alternative agronomic nutrient/manure management practices. Because their contributions to existing conditions are of much lower magnitude than other land-uses, no reductions were allocated to built-up, barren, farmstead, or forested areas.

3. The TMDL considers the impacts of background pollutant contributions

Virginia has identified background loadings as being comprised of loadings from forested land and of a baseline background concentration of 30 counts/100ml applied to the entire stream segment.

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[4]12VAC5-610-90.A.

As can be seen in Table 3, above, a specific existing load has been calculated for forested land areas in the watershed. This load is calculated based on wildlife contributions, and is thus considered to be an appropriate measure of "natural loading" in the watershed. Consequently, no load reductions from forested land loadings were considered. Although a calculation of the projected loading from forested land could be used as a baseline loading factor for the entire watershed, this approach was deemed inappropriate. First, it is assumed that the watershed will never be 100% forested. Additionally, although a forested land-use loading factor was established, Virginia did not feel that a suitable, or pristine, forested reference area was available to support such a broad application. Therefore, Virginia selected a generic baseline loading rate of 30 counts/100 ml, based on the experience of Virginia's contractor, *i.e.*, best professional judgement.

4. The TMDL considers critical environmental conditions.

EPA regulations at 40 CFR 130.7(c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality is protected during times when it is most vulnerable. The selection of a critical environmental condition also generally corresponds to a specific stream flow condition. This allows for the correlation of total available pollutant loads with in-stream concentrations of the pollutant, when the applicable water quality standard is concentration based.

A single critical condition could not be identified for fecal coliforms in Muddy Creek. Elevated fecal coliform levels were observed over a wide range of flow conditions, with general increases in frequency and magnitude observed during both low- and high-flow conditions. These observations support the premise that fecal loading is occurring as the result of both direct release of fecals into the stream (via straight pipes, uncontrolled discharges, cows loafing in the stream, and permitted point sources) and overland flow into the stream during storm events (from fecal coliform built-up on the land). In order to effectively consider this lack of a single critical condition, Virginia developed loading factors based on monthly average build-up rates for each land-use category and monthly average "direct" contributions. The monthly average approach was judged appropriate primarily to account for seasonal variations in agricultural practices.

Monthly average stream loading rates from built-up fecal coliforms were then calculated based on the continuous hydrologic data available for the five-year model calibration period. This five-year period which was judged to adequately cover the range of flow and loading scenarios, and thus produce reliable annual loading rates for each land use category.

5. The TMDL considers seasonal environmental variations

Seasonal variations involve changes in stream flow as result of hydrologic and climatological patterns, and also may reflect changes in local management practices related to pollutant loadings. In the continental United States, seasonally high flow normally occurs during the colder period of winter and in early spring from snow-melt and spring rains, while seasonally low flow typically occurs during the warmer summer and early fall drought periods[5].

Given the lack of a discrete critical condition, and the significant seasonal variations in flow rates within a watershed such as Muddy Creek, daily or monthly calculations of fecal coliform loads to the stream geared toward compliance with the concentration-based water quality standard, are not directly comparable to one another. In situations such as this one, expressing the load allocations on an annual basis, using field-derived or accepted loading coefficients from the literature, is deemed appropriate to account for seasonal variations.

In calculating the average annual loads, Virginia modeled average loading on a monthly basis. The development of monthly average build-up rates for each land-use and for direct loadings in the Muddy Creek watershed not only allowed Virginia to account for seasonal variations in precipitation and stream flows, but also accommodated the consideration of seasonal management practices relating to fecal coliform loading. For instance, field level surveys around Muddy Creek indicated that farmers generally apply manure only during spring and fall months. Loadings to pasture lands during other months are the product of direct deposition from grazing livestock and wildlife. Additionally, use of the stream channel itself by cattle varies a great deal, depending on the time of year. These monthly loadings were subsequently summed to provide average annual loadings of fecal coliforms for each source/land-use.

6. The TMDL includes a margin of safety

This requirement is intended to add a level of safety to the TMDL-development process to account for any uncertainty. Margins of Safety (MOS) may be implicit, built into the modeling process, or explicit, taken as a percentage or portion of the waste-load allocation, the load allocation, or the TMDLs. Since the applicable endpoint for the fecal coliform TMDL in Muddy Creek is a concentration-based criterion (200 counts/100ml), Virginia opted for an explicit MOS by reducing the target criterion for modeling purposes by 5% to 190 counts/100ml. The selected TMDL allocation scenario, therefore, never exceeds 190 counts/100ml, as opposed to 200 counts/100 ml, calculated as the geometric mean of all samples collected during a given 30-day period.

The bacterial load associated with this MOS can be approximated by the equation:

$$TMDL_{200} = WLA + LA + (0.05\ TMDL_{200}),$$

where the MOS = 0.05 $TMDL_{200}$ and $TMDL_{200}$ represents the annual load associated with the 200 #/100ml geometric mean criteria in Virginia's water quality standard for fecal coliform

[5] Section 2.3.3 of the Technical Guidance Manual for Developing Total Maximum Daily Loads, Book 2, Part 1 (EPA 823-B-97-002, 1997).

Solving this equation, the MOS is 4.56×10^{11} counts/year.

Additionally, where loading associated with specific sources could not be readily quantified by direct measurement, or by the available literature, conservative estimates were consistently selected. Thus, an additional MOS is implicit in the model.

7. The TMDL has been subject to public participation

Virginia has developed a standing public notification/public participation process for the development of TMDLs. In keeping with that process, a public meeting, intended to introduce interested parties to an early draft of the TMDL for Muddy Creek, was held in Harrisonburg, VA, on September 16, 1998. This meeting, along with an opportunity for public comment was announced in the *Virginia Register*, and in a local newspaper (the *Harrisonburg Daily News-Record*), and was attending by approximately 85 people. A follow-up public meeting was held at the Mount Clinton School on October 26, 1998, at the request of the County Farm Bureau, and was attended by approximately 250 people.

A third public meeting was held on December 15, 1998, to present the developed TMDL for public comment. The associated public comment period was announced on December 7, 1998, and was eventually extended to March 17, 1999. A final public comment period, reflecting additional revisions to the TMDL was announced in April and closed on May 26, 1999. Virginia received comments from citizens groups, individuals, and interested parties. During this process, the Muddy Creek Citizens Advisory Group was formed with the support of the County Farm Bureau.

8. There is reasonable assurance that the TMDL can be met

Reasonable assurance that the TMDL for Muddy Creek can be achieved can be discussed from two perspectives: (1) the required loading reductions are technically achievable, and (2) adequate resources will be applied to ensure implementation.

Virginia selected the specific source allocations for the preferred load reduction scenario based not only on its belief that the reduction in fecal loadings to Muddy Creek will be protective of human health and meet the fecal coliform standard, but also on the belief that implementation to meet the reduction targets (allocations) for each source is feasible from a practical perspective. While a number of allocation scenarios were considered during development of this TMDL, the final selections ensure the feasibility of this TMDL:

- Although the removal of livestock from riparian areas/streams appears to be the single most significant measure for reducing fecal loading, Virginia refrained from requiring 100% removal of cattle from the streams, to accommodate cattle crossings.

- Virginia depends to a great extent on reductions of loading from barnyard and feedlot runoff, since these sources are controllable via construction of physical flow controls.

- Virginia sought to minimize the reductions to loading associated with agricultural application of manure to crop and pasture lands, given that economically viable alternatives are not yet available.

- Virginia considers 100% removal of loads from failing septic systems and straight pipes reasonable, based on the requirements of Virginia public health laws and VPDES programs.

- Virginia will utilize a phased implementation process, which will allow for evaluation of effectiveness of management practices and refinement of the model, as necessary.

With respect to the phased implementation process, Virginia has identified the reductions in existing loads, in-stream cows, failing septic systems, and uncontrolled discharges, as a Phase I allocation to reduce the WQS violation rate to not more than 10 percent violation of the 1000 count/100 ml criterion. At that time, the monitoring program will shift to two or more samples within a 30-day period to demonstrate compliance with the 200 counts/100 ml geometric mean. At that time, reductions in fecal coliform bacteria nonpoint source loads from various land uses will be required. This is reasonable in that until the effects of the initial load reductions are reflected in lower fecal coliform counts in Muddy Creek, additional monthly samples will not provide additional information and the cost of sampling is not justified.

With respect to the existence of future resources to adequately support implementation of this TMDL, Virginia State Law (the Water Quality Monitoring, Information and Restoration Act of 1998) requires the development of an implementation plan for all approved TMDLs in the Commonwealth. It is EPA's understanding that such a plan for Muddy Creek will be developed during the remainder of 1999. Virginia presently administers a number of water quality-related programs which will be utilized to support the implementation plan for Muddy Creek:

- The Shenandoah-Potomac Tributary Strategy: While the Strategy is targeted to address nutrient loading, most of the prescribed implementation activities address more general agricultural sources of pollution, and thus are applicable to the control of fecal coliforms. Additionally, implementation work in Muddy Creek will be coordinated with the results of a nitrate TMDL for Muddy Creek, anticipated for completion by May, 2000.

- Watershed Restoration Action Strategy (WRAS) for the North River area: Virginia has established a "two-tiered" framework for the development of WRASs, as is required by the Federal Clean Water Action Plan of 1999 for high-priority watersheds. In combination with the Tributary Strategy, the TMDL implementation plan developed for Muddy Creek will be identified as a WRAS. The completion of this WRAS framework for Muddy Creek will ensure the watershed's eligibility for selective funding associated with the CWAP.

- Because the Muddy Creek watershed has been identified as a high priority watershed by Virginia, significant funding associated with Virginia's Water Quality Improvement Fund, and with Virginia's agricultural cost share and incentives programs will be targeted to this watershed.

- The Muddy Creek Citizens Advisory Committee, formed during the winter of 1998-1999, has taken an active role in development of the TMDL and the ensuing implementation plan. The Committee has stated that "...we are ready to improve the quality of the creeks, streams and rivers in our back yards, let us take the lead..."[6]

[6]Letter form Citizens Advisory Committee, via the Rockingham County Farm Bureau, to Virginia DEQ (Charles Martin), dated June 7, 1999.

Fecal Coliform TMDL for Muddy Creek, Virginia

Revised Final Report

December 2000

NOTE:

This revised final report for the Muddy Creek fecal coliform TMDL was modified from the original version published in July 1999 by the addition of Appendix C – "Revalidation of the Fecal Coliform Bacteria Total Maximum Daily Load (TMDL) for the Muddy Creek Watershed in Virginia".

The objective of this study was to revalidate the fecal coliform TMDL allocations for Muddy Creek using permitted levels for the waste load allocations (WLA). The original fecal coliform TMDL, as approved by EPA in August 1999, utilized the observed current loads for the WLA. It was the conclusion of the investigators that no modifications of the load allocations in the fecal coliform TMDL for Muddy Creek will be required to accommodate the permitted load of the major point source.

- The Muddy Creek Citizens Advisory Committee, formed during the winter of 1998-1999, has taken an active role in development of the TMDL and the ensuing implementation plan. The Committee has stated that "...we are ready to improve the quality of the creeks, streams and rivers in our back yards, let us take the lead..."[6]

[6]Letter form Citizens Advisory Committee, via the Rockingham County Farm Bureau, to Virginia DEQ (Charles Martin), dated June 7, 1999.

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TABLES

FIGURES

EXECUTIVE SUMMARY

Fecal Coliform Impairment

Muddy Creek has been placed on the Commonwealth of Virginia's 1998 303(d) list of impaired waterbodies because of violations of the fecal coliform bacteria water quality standard. Sufficient exceedances of this standard were recorded at Virginia Department of Environmental Quality (VADEQ) monitoring stations to indicate that the stream does not support primary contact recreation (swimming, wading, fishing, crayfish catching, etc.). The applicable state standard specifies that the number of fecal coliform bacteria shall not exceed a maximum allowable level of 1,000 counts per 100 milliliters (mL). A review of available monitoring data for the study area indicates that fecal coliform bacteria are consistently elevated above the 1,000 counts/100mL standard. In modeling simulations, a direct comparison with the geometric mean standard of 200 cfu/100 mL could be used.

Sources of Fecal Coliform

Potential sources of fecal coliform include both point source and nonpoint source contributions. Nonpoint sources include wildlife (deer), grazing cattle, land application of cattle manure and poultry litter, urban/suburban runoff, failed or malfunctioning septic systems, and "uncontrolled discharges" (straight pipes, dairy parlor waste, manure disposal in sinkhole dumps, etc.). Permitted point sources include the Mount Clinton Elementary School and the Wampler Foods, Inc., poultry slaughtering and processing facility.

Water Quality Modelling

The US Environmental Protection Agency's (US EPA) BASINS Nonpoint Source Model (NPSM) was selected as the modelling framework to simulate existing conditions and perform TMDL allocations. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of the continuous simulation model allowed consideration of seasonal aspects of precipitation patterns within the watershed.

Daily flows from the US Geological Survey gage (#01621050) on Muddy Creek at Mt. Clinton, VA, were used to calibrate hydrologic flows for the Muddy Creek watershed in the NPSM model, thereby improving confidence in computed stream flows generated by the model. The representative hydrologic period used for this TMDL was 1991 through 1995, covering a range of hydrologic and climatic conditions. For purposes of modelling watershed inputs to instream water quality, the Muddy Creek watershed was divided into eight subwatersheds. Background water quality conditions were included in the TMDL analysis, as loadings from forested lands within the watershed.

Existing Loadings and Water Quality Conditions

Deer populations, numbers of cattle and other livestock, and information on livestock and manure management practices for the Muddy Creek watershed were used to calculate fecal coliform loadings from land-based nonpoint sources in the watershed. The estimated fecal coliform production and accumulation rates due to these sources were calculated for the watershed and incorporated into the model. To accommodate the structure of the model, calculation of the fecal coliform accumulation and source contributions on a monthly basis accounted for seasonal variation in watershed activities such as livestock grazing and land application of manure.

Also represented in the model were direct nonpoint sources of failing septic systems, uncontrolled sources, and cattle in the stream. Of the two point sources, Mt. Clinton Elementary School was not included in the model because it has never discharged to the stream system and because the school is scheduled for closure. Using monitoring data recorded for the Wampler Foods facility's discharge permit, a representative flow rate and fecal coliform concentration were determined and used in the model.

Contributions from all of these sources were represented in the model to establish existing conditions for the watershed over the representative hydrologic period. Under existing conditions, the NPSM model provided a comparable match to VADEQ's monitoring data, with output from the model indicating violations of the both the instantaneous and geometric mean standards throughout the watershed.

Load Allocation Scenarios

The next step in the TMDL process was to detemine how to proceed from existing watershed conditions to reduce the various source loads to levels that would result in attainment of the water quality standards.

Because Virginia's fecal coliform standard does not permit any percentage exceedance of the standard, modelling was conducted for a target value of 0% exceedance of the 200 counts/100 ml geometric mean standard. Scenarios were evaluated to predict the effects of different combinations of source reductions on final instream water quality. Modelling of these scenarios provided predictions of whether the reductions would achieve the target of 0% exceedance. When a scenario produced the desired target value, the associated reductions were then allocated among the various source inputs and land uses.

In developing an allocation scenario, it is necessary to examine both dry weather and wet weather flow, because the relative impacts of different sources may change with flow. Therefore, the initial focus was on sources which impact low flow concentrations, because modelling of existing conditions indicated significant low flow impacts on violations of the standard.

Primary sources which impact low flow concentrations in Muddy Creek are point sources, failed septic systems, wildlife, uncontrolled sources, and cattle in the stream. Point sources and wildlife contribute relatively small amounts to the fecal coliform concentrations in Muddy Creek. Therefore, in the allocation scenario reductions are made from septic systems, uncontrolled sources, and cattle in the streams. Because of significant low flow impacts on violations of the standard, the percent reductions from these sources are relatively high: 100% for failed septic systems, 100% for uncontrolled sources, and 99.3% for cattle in the streams.

Reduction of wet weather inputs requires the following percent reductions from land uses within the watershed: Cropland 13%, Loafing Lots 80%, Pasture 1 41%, Pasture 2 42%, Pasture 3 42% (see Appendix A for pasture classifications). Because their contributions to existing conditions are of much lesser magnitude, no reductions are allocated for Built-up, Barren, Farmstead, or Forested land uses.

Margin of Safety

To provide for scientific uncertainties, a margin of safety was addressed in both the source inputs and the allocation modelling. Actual numbers are unknown for "uncontrolled sources" such as straight pipes, dairy parlor waste discharges, and sinkhole dumps, although their presence is suggested by monitoring and limited field information. Suspected but unquantified sources were represented as straight pipes in the model. Six of these sources were included. A target value of 190 counts/100 ml was used in developing scenarios for 0% exceedance, allowing a 5% margin of safety relative to the geometric mean standard.

Recommendations for TMDL Implementation

VADEQ is responsible for developing an implementation plan for the Muddy Creek TMDL. Watershed stakeholders will have opportunities to provide input and participate in development of the implementation plan, with support from regional and local offices of VADEQ, VADCR and other participating assistance agencies. Current regulations of the Virginia Department of Health require correction of all straight pipes and failed septic systems, and it is recommended that all such sources be brought into compliance. Dairy parlor waste direct discharges and sinkhole dumps should be identified and corrected. Because it was difficult to obtain accurate numbers for these four sources during development of the TMDL, ground proofing may be needed as part of the implementation.

Implementation of best management practices (BMPs) in the Muddy Creek watershed will occur in phases. The benefit of phased implementation is that as stream monitoring continues, accurate measures of progress achieved are recorded. Progress can be evaluated and adjustments can be made. Additionally, given the uncertainties existing in the developed TMDL model, phased implementation and continued monitoring can provide a measure of quality control. The target for the first phase of implementation in the Muddy Creek watershed is a reduction of violations of the 1000 counts/100ml standard to less than 10%. To provide guidance for phased implementation, a scenario depicting this 10% target is included as part of the modelling for the Muddy Creek TMDL. The Phase 1 allocation requires no reduction in existing loads from land uses within the watershed. Inputs from failed septic systems and uncontrolled direct sources must be completely eliminated, and direct source inputs from cattle in streams must be reduced by 94.4%.

Regarding implementation of the TMDL, many of the actions which would be required to reduce fecal loadings from cattle in the stream would also reduce loads from pasture. Stream fencing and alternative watering devices will result in improved streambank conditions, less deposit of fecal matter in areas directly adjacent to the stream, and buffering due to improved pasture conditions in the near-stream areas. Therefore, it may be possible to achieve reductions in loading for both the cattle in the stream during dry weather and for the pasture areas during wet weather with the same set of BMPs. A variety of BMPs including runoff diversion can reduce loafing lot loadings. Substantial load reductions from loafing lots may alleviate the need for reductions from cropland, and followup monitoring can indicate whether cropland reductions are necessary. Several participants in public meetings have expressed interest in innovative treatment methods for manure.

Cost-share funds are available for implementation of agricultural BMPs. On a competitive basis, Section 319 grant funds are available for demonstration and implementation of both agricultural and nonagricultural BMPS, and Virginia Water Quality Improvement Act funds are available for implementation of a variety of BMPs.

Reasonable Assurance of Implementation

Consistent with Virginia's multi-tiered approach to Watershed Restoration Action Strategy (WRAS) development, the Muddy Creek TMDL implementation plan will serve as a second-tier or watershed level WRAS. The Muddy Creek WRAS will identify goals and processes for addressing water quality impairments in the creek and it will address the WRAS criteria or elements set forth in EPA guidance issued on June 9, 1998.

As set out in Virginia's Continuous Planning Process (CPP), the Muddy Creek TMDL will be incorporated into the Shenandoah-Potomac revised Water Quality Management Plan (WQMP). Pursuant to Virginia law, an implementation plan is required to be developed following adoption of the TMDL into that WQMP. A stakeholder's advisory group (Muddy Creek Citizens Watershed Advisory Group) will assist Virginia DEQ and DCR with development of the implementation plan. Under EPA's Unified Watershed Assessment process, the Muddy Creek watershed is a high priority for funding, and the TMDL implementation plan will serve as a Watershed Restoration Action Strategy, which will direct the use of funding.

Public Participation

An initial public meeting to discuss proposed development of the Muddy Creek TMDL for fecal coliform was held on 16 September, 1998. The Rockingham County Farm Bureau, with assistance from the Virginia Farm Bureau, conducted a second public meeting on 26 October, 1998. On 15 December, 1998, a public meeting was held to present the completed TMDL, and a draft report was made available in February, 1999. Questions, comments, and/or transcripts from these meetings will be made available. During early 1999, a Muddy Creek Citizens Watershed Advisory Group was formed. This group has reviewed and responded to the draft TMDL and will work with state and local agencies in developing an implementation plan for the watershed. The Farm Bureau and the Shenandoah Valley Soil and Water Conservation District have also suggested forming a volunteer water quality monitoring group. Members of the Rockingham County Board of Supervisors have met with VADEQ and VADCR staff to discuss local planning and financial needs for TMDL implementation.

ACKNOWLEDGMENTS

The Muddy Creek TMDL Establishment Workgroup members are:

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1.0 INTRODUCTION

1.1 Background

Levels of fecal coliform bacteria can become elevated in waterbodies as a result of both point and nonpoint sources of pollution. Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are not meeting designated uses under technology-based controls. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish water-quality based controls to reduce pollution from both point and nonpoint sources and restore and maintain the quality of their water resources (USEPA, 1991a).

VADEQ has identified Muddy Creek as being impacted by fecal coliform bacteria for a length of 10.36 miles, as reported on the 1998 303(d) list of water quality limited waters (VADEQ, 1998). The impaired segment begins in the headwaters and extends to the confluence with Dry River. Muddy Creek is prioritized as "high" on the list for TMDL development and carries an agency waterbody code of VAV-B22R. Waters ranked high priority are targeted for TMDL development during the biennium.

The Muddy Creek watershed is located in Rockingham County, Virginia, approximately 10 miles to the west-northwest of Harrisonburg, Virginia (Figure 1.1). Muddy Creek flows south to its confluence with the Dry River, which discharges to the North River approximately 2.25 miles farther to the south. The North River flows to the South Fork of the Shenandoah River, a tributary of the Potomac River, which eventually discharges into the Chesapeake Bay. The Muddy Creek watershed is located within the South Fork Shenandoah hydrologic unit (No. 2070005). The land area of the Muddy Creek watershed is approximately 20,025 acres, with forest and agriculture as the primary land uses. Rockingham County is the largest agricultural county in Virginia for dairy and poultry production (VADEQ, 1997). A majority of the agricultural land is located in the central and eastern portions of the watershed, while the forested areas are generally located in the western portion.

1.2 Applicable Water Quality Standards

All waters of Virginia, including Muddy Creek, are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish) (9VAC 25-260-10). Muddy Creek was listed on the Virginia Department of Environmental Quality (VADEQ) 1998 303(d) list as being impaired by fecal coliform bacteria. Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported (VADEQ 1998).

Virginia's water quality standard for fecal coliform bacteria in Muddy Creek can be applied in one of two ways. First, the fecal coliform bacteria count shall not exceed a geometric mean of 200 per 100 ml of water for two or more samples taken over a 30-day period. (For commonly used laboratory methods, bacteria "count" refers to the counting of bacterial colonies grown in laboratory culture from the water sample, with the assumption that each colony originates from a single viable bacterium. For further explanation, see Standard Methods for the Examination of Water and Wastewater, APHA 1985.) Second, for data sets consisting of single samples taken monthly, the fecal coliform bacteria count shall not exceed 1,000 per 100 ml for any single sample. (9 VAC 25-260-170). Most of VADEQ's ambient water quality monitoring is done on a monthly or quarterly basis. This sampling frequency does not provide the two or more samples within 30 days needed for use of the geometric mean part of the standard. Therefore, VADEQ uses the 1,000 per 100 ml part of the standard in the 303(d) assessment of the fecal coliform bacteria monitoring data. Waters are listed on Virginia's 303(d) List as impaired by analysis of compliance with the 1000 per 100 milliliters criteria.

Prior to 1992 Virginia's fecal coliform standard only had one criterion, the geometric mean of 200 fecal coliform bacteria per 100 milliliters for 2 or more samples within a 30 day period. VADEQ's monthly monitoring program was and remains designed to collect one sample per month. However, this program of monthly monitoring did not produce sufficient data to allow an assessment of compliance with Virginia's fecal coliform standard based on 2 or more samples per month.

To correct this situation, the fecal coliform standard was modified by adding an additional criterion, the 1000 per 100 milliliters maximum, if only one sample is available during a 30 day period. This criterion was added to the standard specifically to allow compliance to be assessed based on the data from our monthly monitoring program.

US EPA's 303(d) listing guidance allows waters with violation rates of 10% or less to be classified as fully supporting of all the designated uses. In Virginia's water quality standard for fecal coliform bacteria, the 1000 counts per 100 ml criterion is written with "no tolerance" and a single sample exceeding 1000 is a violation of the standard. Most of VADEQ's monitoring stations have at least one or more sample exceeding 1000 during the five year assessment period. Without the 10% violation exception provided by EPA's listing guidance, nearly all waters monitored in Virginia would be listed as impaired for violating the fecal coliform standard.

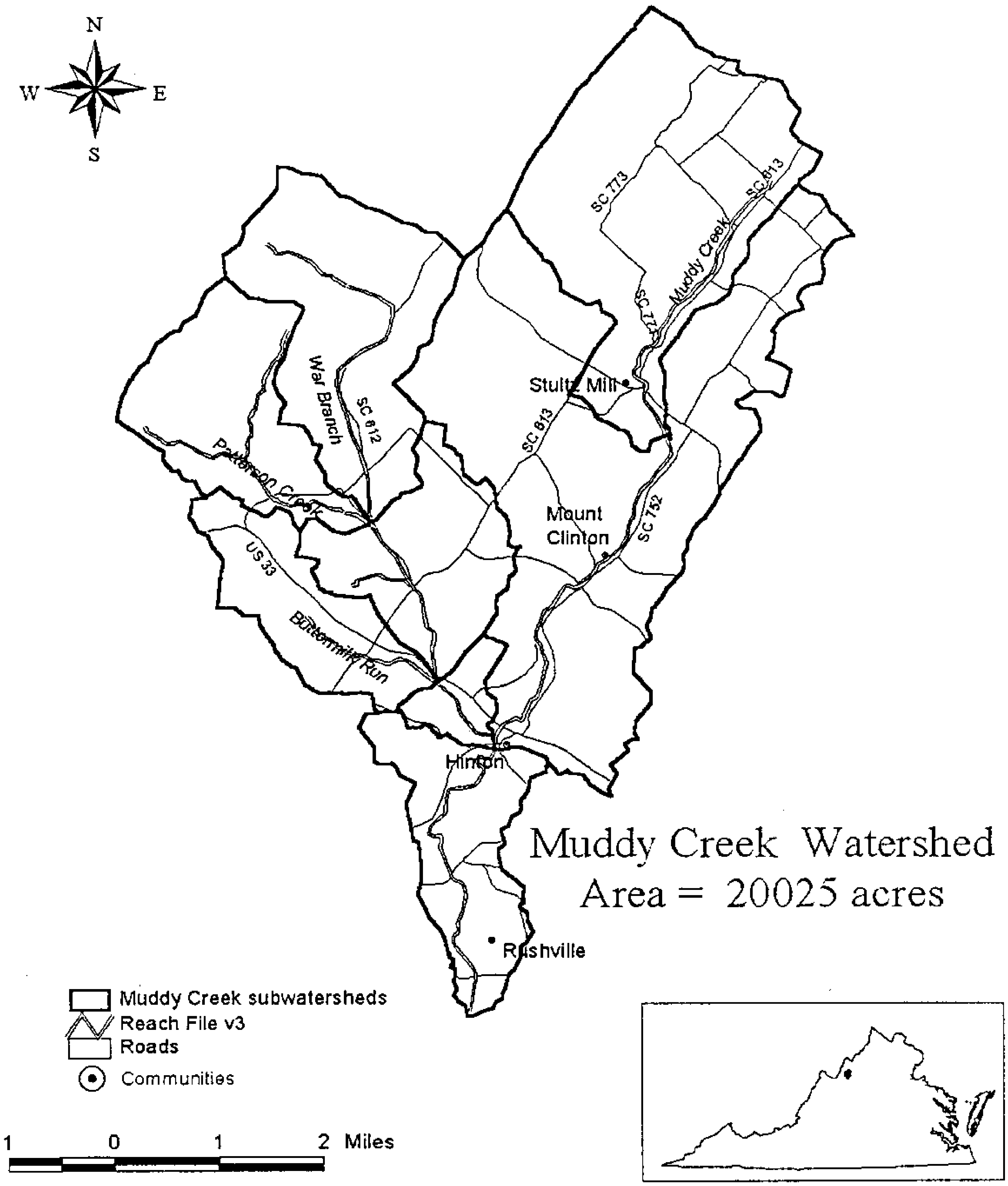
The language for TMDL development contained in Section 303(d) of the Clean Water Act and EPA's 303(d) regulation clearly states that a TMDL must result in the attainment of the water quality standard. The 10% violation exception allowed in EPA's guidance for listing waters does not apply to TMDL development. Therefore a TMDL based on the 1000 counts per 100 ml criterion must have a zero violation rate to meet Virginia's water quality standard and comply with EPA's 303(d) regulation. A TMDL with a zero violation rate would be so stringent that it would be impossible to implement.

Application of the geometric mean criterion counts per 100 ml dampens the high values in a data set and Virginia's water quality standard is not violated by a single high value. Therefore, the instream fecal coliform bacteria criterion selected for this TMDL is the geometric mean of 200 counts per 100 ml.

VADEQ applies the geometric mean criteria of 200 fecal coliform bacteria to monitoring data generated from special monitoring programs or projects designed to produce multiple samples over periods shorter than a month. Also, model simulations can generate multiple data points within a 30 day period for application of the geometric mean criteria.

TMDL calculations and modeling predictions which are based on the geometric mean are to be evaluated and verified by VADEQ's water quality monitoring program designed to produce 2 or more samples within a 30 day period.

Figure 1.1 Study Area: Muddy Creek Watershed
Rockingham County, Virginia



2.0 TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Selection of a TMDL Endpoint and Critical Condition

Muddy Creek was placed on the Virginia 1998 303(d) list due to elevated levels of fecal coliform bacteria recorded at VADEQ ambient water quality monitoring stations. The Muddy Creek TMDL addresses 10.36 miles of stream from the headwaters to the confluence with Dry River that do not support the swimming (primary contact recreation) use.

One of the major components of a TMDL is the establishment of instream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. Instream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. The endpoints allow for a comparison between observed instream conditions and conditions that are expected to restore designated uses. The endpoints are usually based on either the narrative or numeric criteria available in state water quality standards. For the Muddy Creek TMDL, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations. The instream fecal coliform target for this TMDL is a geometric mean of 200 counts/100 ml, with 0% violations.

Because fecal coliform violations within the Muddy Creek watershed are attributed to both nonpoint and direct instream sources, the critical condition used for the modeling and evaluation of stream response was represented by a multi-year period. Critical conditions for waters impacted by nonpoint sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. The 1991-1995 period represents both low flow conditions as well as wet-weather conditions and encompasses a range of wet and dry seasons. Therefore, the period was selected as representing the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed.

2.2 Discussion of Instream Water Quality

This section provides an inventory and analysis of available observed instream fecal coliform monitoring data in Muddy Creek. This section includes the following:

- inventory of water quality data
- summary of water quality data
- summary of frequency of water quality violations

2.2.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information are:

- Four VADEQ instream monitoring stations located in Muddy Creek
- Water quality sweep conducted by VADEQ in September 1998

- Report by VADEQ titled *Total Maximum Daily Load Study on Six Watersheds in the Shenandoah River Basin*

VADEQ Instream Water Quality Monitoring Stations

Table 2.1 summarizes the fecal coliform samples collected at the four VADEQ instream monitoring stations. Monitoring site locations are shown in Figure 2.1. Instream fecal coliform samples for Muddy Creek are available from November 1970 to present. Samples collected prior to February 1995 were analyzed with the most probable number (MPN) technique and samples collected after February 1995 at stations 1BMDD000.40 and 1BMDD005.81 were analyzed for fecal coliform concentration with the faster and more accurate membrane filter technique (APHA, Standard Methods, 1985). Because different laboratory analytical methods and different dilutions may have influenced apparent detection limits, care must be taken when directly comparing fecal coliform maximum values for data collected during these different time periods. It should be noted that there are differences in the maximum detection limits before and after February 1995 and, at Station 1BMDD001.65, before and after September 1971.

Table 2.1. Instream water quality stations in Muddy Creek

Stations	Location	Frequency	Status	Date
1BMDD000.40	Route 737 Bridge	Monthly	In use	7/91-Present
1BMDD005.81	Route 726 Bridge at USGS gage at Mount Clinton	Monthly	In use	9/93-Present
1BMDD001.65	Route 734 Bridge	Approx. Monthly	Not in use	11/70-3/79
1BMDD005.15	Route 875 Bridge near Hinton	Monthly	Not in use	7/91-8/93

Water Quality Sweep, September 1998

On September 10, 1998, VADEQ conducted a 1-day sampling program within the Muddy Creek watershed. The objective was to assess water quality conditions at 15 different locations throughout the watershed and to determine if stream bottom sediments of Muddy Creek and its tributaries could be contributing fecal coliform to the overlying water column through resuspension. Figure 2.2 shows the location of the sampling sites.

Additional Information

An additional source of information was a study by VADEQ titled *Total Maximum Daily Load Study on Six Watersheds in the Shenandoah River Basin.* The objectives of the study were to assess current conditions of streams in the study area, investigate any trends in water quality, and provide information for developing TMDLs. The data used in the study were from ambient monitoring stations operated by VADEQ.

Figure 2.1 DEQ Muddy Creek Water Quality Monitoring Stations

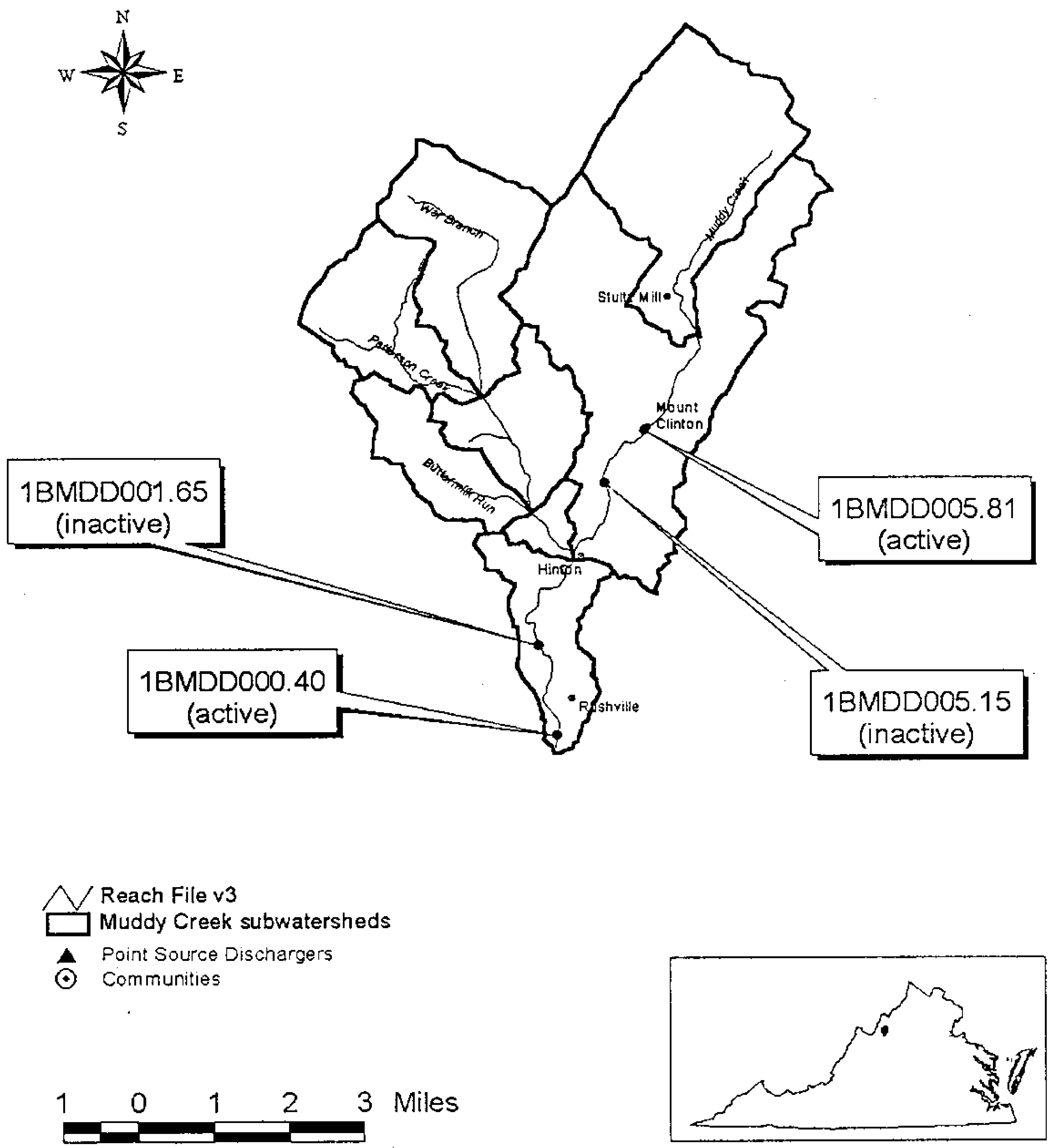
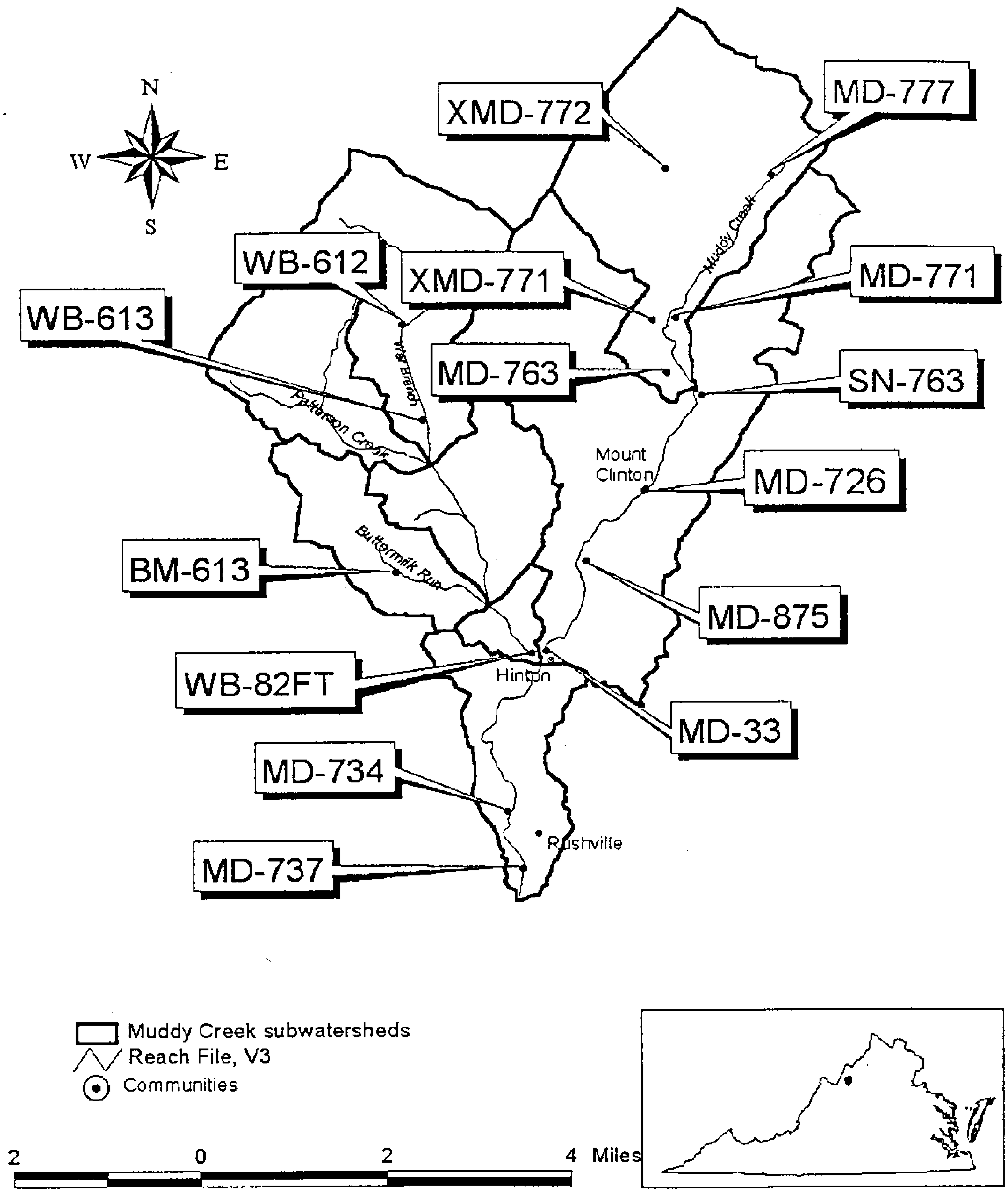


Figure 2.2 Water Quality Monitoring Sweep Station Locations



2.2.2 Summary of Instream Water Quality Monitoring Data

Of the inventoried stations, two out of the four VADEQ stations are currently in use. VADEQ stations 1BMDD000.40 and 1BMDD005.81 are operational; stations 1BMDD001.65 and 1BMDD005.15 were discontinued in March 1979 and August 1993, respectively.

The maximum, minimum, average, and median for available water quality data from the four instream monitoring stations were calculated, and the results are presented in Table 2.2. The average fecal coliform count was higher than the median for all stations, indicating the presence of extremely high values. In addition, the median ranged from 900 to 3,500 counts/100 ml indicates that the fecal coliform counts consistently violates the 1,000 count/100 ml standard.

There is a limited amount of flow data corresponding to water quality data for the Muddy Creek watershed. For the years for which water quality and flow data are available, analysis of the data does not indicate an obvious relationship between flow and fecal coliform concentration. Elevated levels of fecal coliform occur during a range of flow conditions, indicating impacts from both diffuse nonpoint sources and direct discharge of fecal coliform loading.

Table 2.2 Summary of Muddy Creek instream water quality data

	Discontinued		**Operating**	
Parameter	**Station 1BMDD001.65**	**Station 1BMDD005.15**	**Station 1BMDD000.40**	**Station 1BMDD005.81**
Total No. of Samples	83	24	88	63
Minimum	100	100	45	20
Maximum	8,000	8,000	16,000	16,000
Median	900	2,550	3,500	3,100
Mean	2,211	3,496	5,592	9,556

VADEQ Water Quality Sweep of September 1998

Fifteen sampling locations within the Muddy Creek watershed were chosen based on accessibility to the streams and a desire to obtain samples from locations representing the range of conditions present in the watershed (e.g., intense agricultural areas, stream source areas, forested areas, Muddy Creek tributaries).

On September 10, 1998, at each chosen sampling site, one water sample was collected at a depth of approximately 10 to 20 cm below the surface of the water. Additionally, the bottom material was disturbed to suspend sediment in the water column, and a sample of bottom water just above the disturbed spot was collected. At the time of the September 10, 1998, sampling there had reportedly been no precipitation in the area within the previous 24 hours. Sampling locations, sample identification numbers and results are shown in Table 2.3.

Analysis by VADEQ of the water samples with suspended sediment (SS Samples) was performed using the most probable number (MPN) method, whereas analysis of the shallow water column samples (SWC samples) was performed using the membrane filtration method (Roger Stewart, e-mail dated September 14, 1998). According to Standard Methods, both analyses give the same results. Because quality control for field sampling, dilutions, analyses, and other procedures was well documented for this sweep survey, SS and SWC samples could be directly compared. The membrane filter method is the most economical analysis, but it cannot be used for samples with suspended sediment. Two dilutions were run on the SWC samples, including 1.0 ml and 0.1 ml dilutions. A summary of the results is presented in Table 2.3, indicating that only 3 of the 15 SWC samples in the 1.0 ml and 4 of the 15 SWC samples in the 0.1 dilution contained fecal coliform concentrations less than the 1,000 counts/100 ml standard. These three sample locations include two located in forested areas and one located in the headwaters of Muddy Creek. Fecal coliform concentrations for the other SWC samples exceeded the standard, with the highest counts found in the lower portions of the watershed. The results measured for the SWC samples were generally consistent with concentrations measured by VADEQ at its water quality sampling stations on Muddy Creek.

Comparison of the water column samples (before and after resuspension of sediment by agitation) suggests that stream bottom materials potentially contain additional storage of fecal coliform bacteria that could be released to the water column by storm turbulence, animals walking in the stream, or other factors. At 13 of the 15 sampling locations, SS samples contained fecal coliform concentrations in excess of the fecal coliform concentrations detected in the SWC samples. The data also show high concentrations of fecal coliform bacteria in bottom water after resuspension of sediment at locations where fecal coliform bacteria would not be expected (in forested areas and at the source of Muddy Creek).

VADEQ Water Quality Study

Between 1993 and 1996 VADEQ conducted a water quality study of six watersheds in the Shenandoah River basin, including the Muddy Creek watershed. The study included monitoring for fecal coliform at the 1BMDD000.40 and 1BMDD005.81 stations. VADEQ used flow measurements from the USGS gage at the 1BMDD005.81 location and measured flow at the 1BMDD000.40 location at the time sampling occurred. Fecal coliform values at Station 1BMDD000.40 exhibit a general pattern of seasonal variation, with higher values in summer and lower values in winter (VADEQ 1997). A similar pattern was recorded at Station 1BNDD005.81 (VADEQ 1997). This pattern suggests impacts on instream counts from both nonpoint, precipitation-driven sources and direct discharges.

Table 2.3. VADEQ water quality sweep conducted in 1998

No.	Description	Id	Bottom Water concentrations (resuspension)	Water concentrations (1ml dilution)	Water concentrations (0.1ml dilution)
1	Muddy Creek, immediately upstream of Route 737 bridge near Rushville. Agricultural area - cow pasture.	MD-737	>16,000	>8000	58,000
2	Duplicate of MD-737	MD-737 DUP	>16,000	>8000	27,000
3	Muddy Creek, immediately upstream of Route 734 bridge. Steep pasture and trees.	MD-734	>16,000	>8000	22,000
4	Muddy Creek, immediately upstream of Route 33 bridge in Hinton. Some pasture, with riparian vegetation present. Buildings including Wampler Foods, Inc. nearby.	MD-33	>16,000	>8000	13,000
5	War Branch, 82 feet upstream of confluence with Muddy Creek in Hinton. Riparian vegetation present on both sides of stream.	WB-82FT	>16,000	7,900	12,000
6	Muddy Creek, immediately upstream of Route 875 bridge, below Mt. Clinton. Agricultural area - cow pasture.	MD-875	>16,000	7,500	5,000
7	Muddy Creek at Route 726 bridge at Mt. Clinton. Agricultural area - cow pasture with direct access to stream.	MD-726	>16,000	7,200	14,000
8	Snapp Creek, immediately below Route 763 bridge near Fairview Church. Agricultural area - cornfields and cow pasture with thick riparian vegetation present.	SN-763	>16,000	1,400	<1000
9	Muddy Creek immediately below Route 763 bridge at Stultz Mill. Agricultural area - cow pasture with direct access to stream.	MD-763	>16,000	3,300	3,000
10	Unnamed tributary of Muddy Creek immediately above Route 771. Open grassy area above sampling point.	XMD-771	5,400	1,800	1,000
11	Muddy Creek immediately above confluence with unnamed tributary and below Route 771. Forested area.	MD-771	9,200	500	<1000
12	Immediately downstream of source of Muddy Creek (house built over spring). Residential yard.	MD-777	5,400	<100	<1000
13	Unnamed tributary of Muddy Creek, immediately below confluence with another unnamed tributary, and immediately above Route 772 bridge. Riparian vegetation upstream of sampling point.	XMD-772	>16,000	3,700	7,000
14	War Branch, immediately upstream of Route 612 bridge. Forested area.	WB-612	5,400	200	<1000
15	War Branch, immediately upstream of Route 613 bridge near intersection of Route 726. Agricultural area - cow pasture.	WB-613	5,400	1,000	2,000
16	Buttermilk Run immediately upstream of Route 613 bridge. Agricultural area - cow pasture.	BM-613	>16,000	2,300	4,000

2.2.3 Summary of Frequency of Violations at the Monitoring Stations

A summary of frequency of violation of the single sample standard of 1,000 counts/100 ml and the geometric mean of at least two samples (200 counts/100 ml) is presented in Table 2.4.

Table 2.4. Frequency of fecal coliform violation at Muddy Creek instream monitoring stations for the applicable water quality standards

Station	1,000 counts/100 ml			200 counts/100 ml			Period of record
	Obs.	No. of violations	%	Obs.	No. of violations	%	
1BMDD000.40	88	63	72	38	36	95	7/91-10/98
1BMDD001.65	83	42	50	40	37	93	11/70-3/79
1BMDD005.15	24	18	75	8	6	75	7/91-8/93
1BMDD005.81	63	45	71	34	30	88	9/93-10/98

Seasonal Analysis

Time series plots of the fecal coliform data collected at the 1BMDD000.40, 1BMDD001.65, 1BMDD005.15, and 1BMDD005.81 monitoring stations are shown in Figures 2.3 through 2.6, respectively. The following is a summary of the observed trends in the time series plots:

- At stations 1BMDD000.40 and 1BMDD005.81 (Figures 2.3 and 2.6) the post-1995 instream fecal coliform concentration increase may be due to a change in the sample analysis methods. A difference in apparent detection limits is also noted in the data from Station 1BMDD001.65. As mentioned in the discussion accompanying Table 2.1, different laboratory analytical methods, different dilutions, and other factors may have influenced the apparent maximum detection limits for several different time periods in the monitoring record. For this reason, care must be taken when directly comparing fecal coliform data collected during these different time periods.

- Fecal coliform data for all stations indicate seasonal variation, with higher instream fecal coliform concentrations occurring during the summer months and lower concentrations typically occurring during the winter months.

- The overall average instream fecal coliform concentration in Muddy Creek during the winter months was 1,753 counts/100 ml prior to 1995 and 2,834 counts/100 ml post 1995.

- During the summer months, the overall average instream fecal coliform concentration in Muddy Creek was 2,578 counts/100 ml prior to 1995 and 12,719 counts/100 ml post 1995.

- Fecal coliform testing is designed to bracket the water quality standard of 1,000 counts/100ml. Maximum counts that can be read from these designed tests are 6,000 or 8,000 or 16,000 counts/100ml. Where fecal coliform counts are equal to these maximum numbers, the actual fecal coliform count could be much higher.

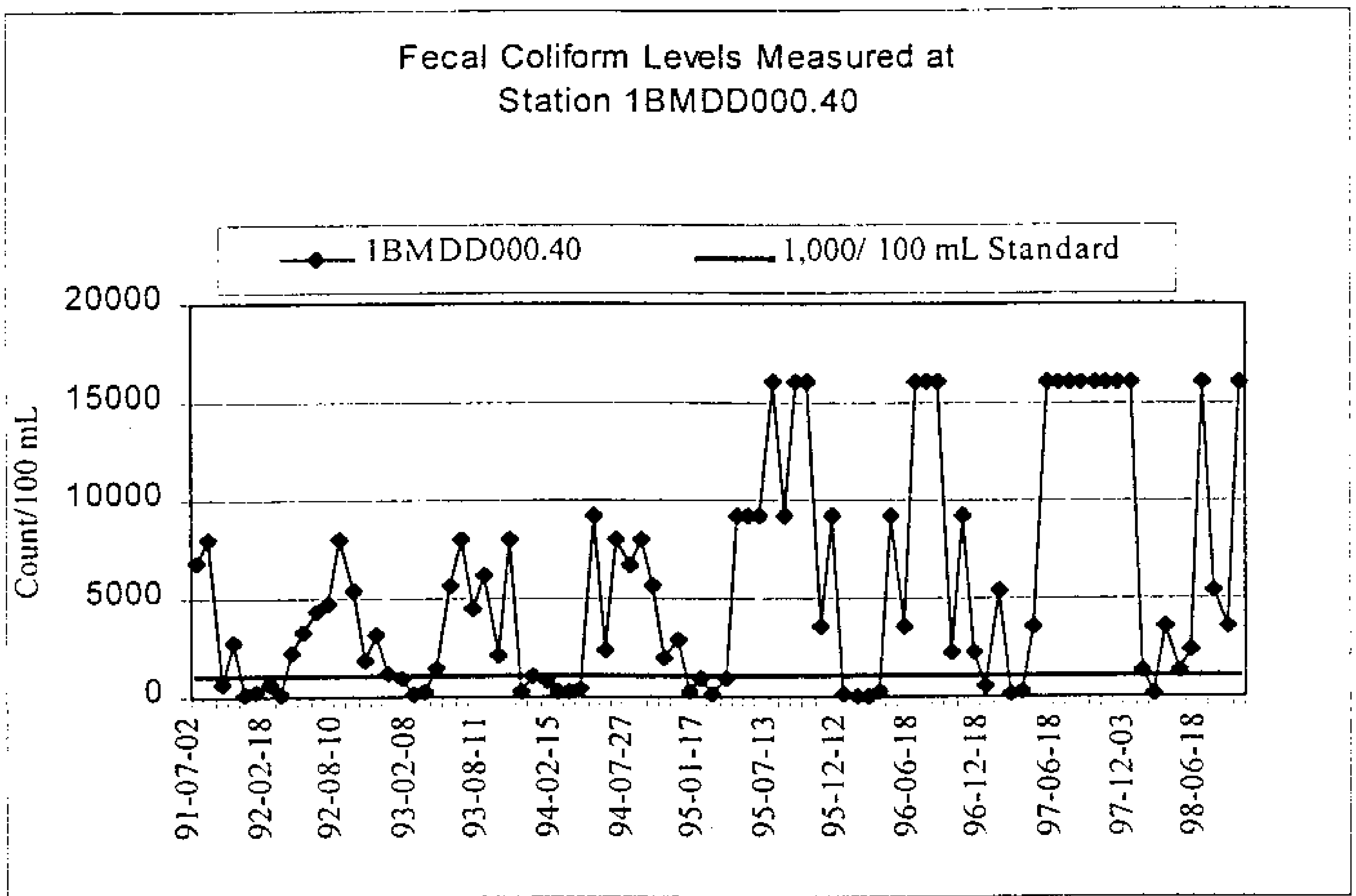


Figure 2.3. Observed fecal coliform concentrations at station 1BMDD000.40

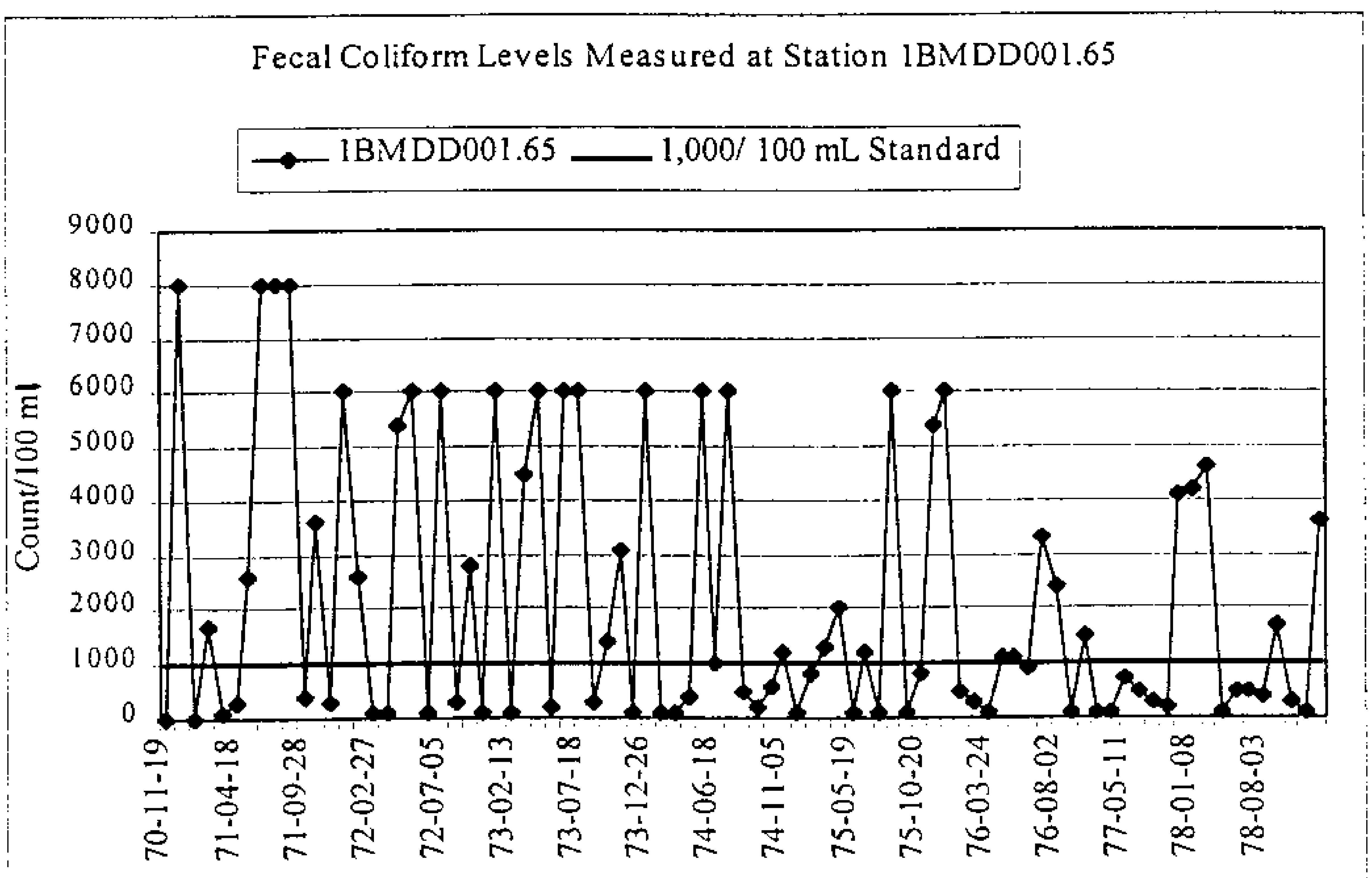


Figure 2.4. Observed fecal coliform concentrations at station 1BMDD001.65

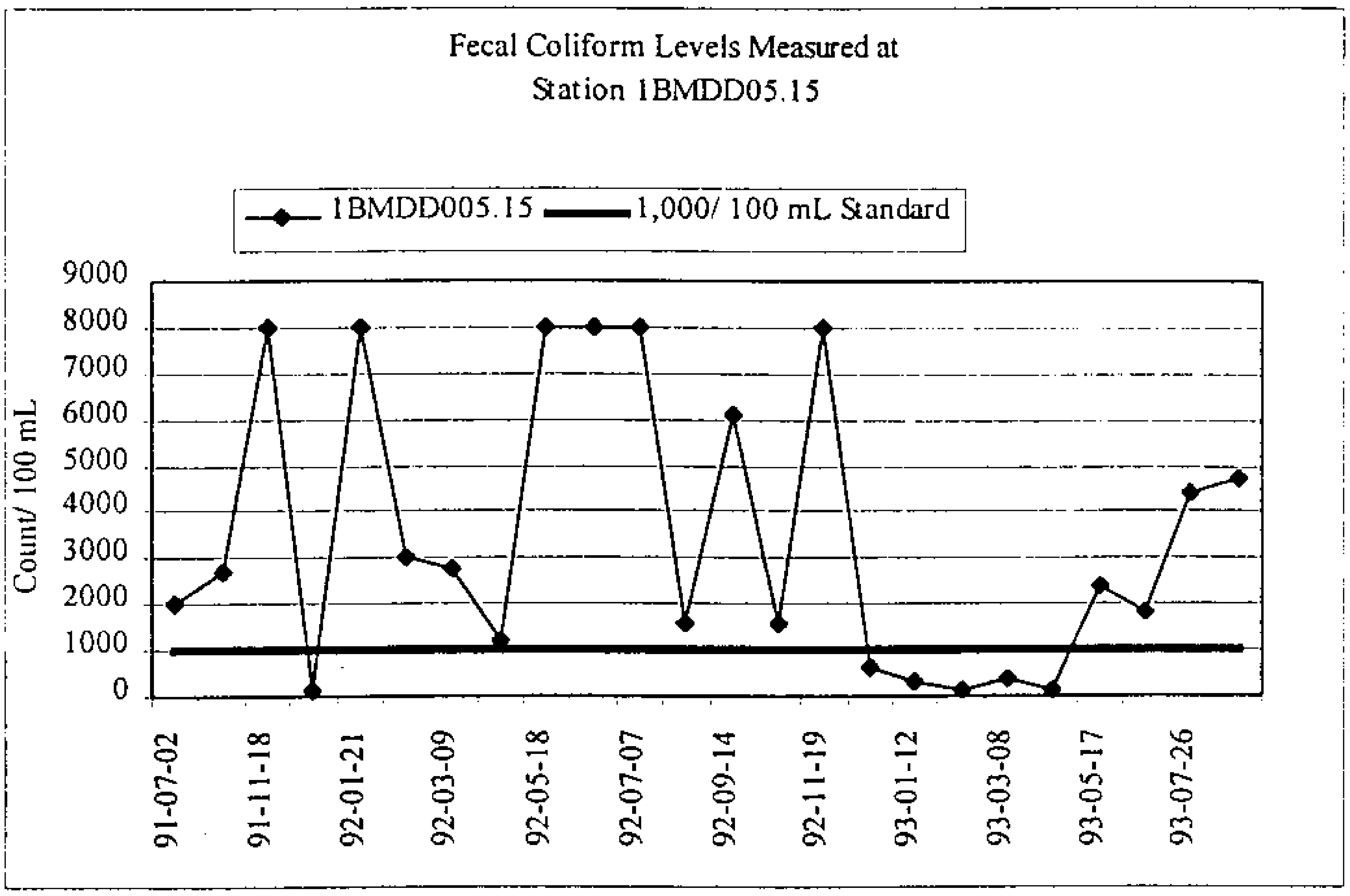


Figure 2.5. Observed fecal coliform concentrations at station 1BMDD005.15

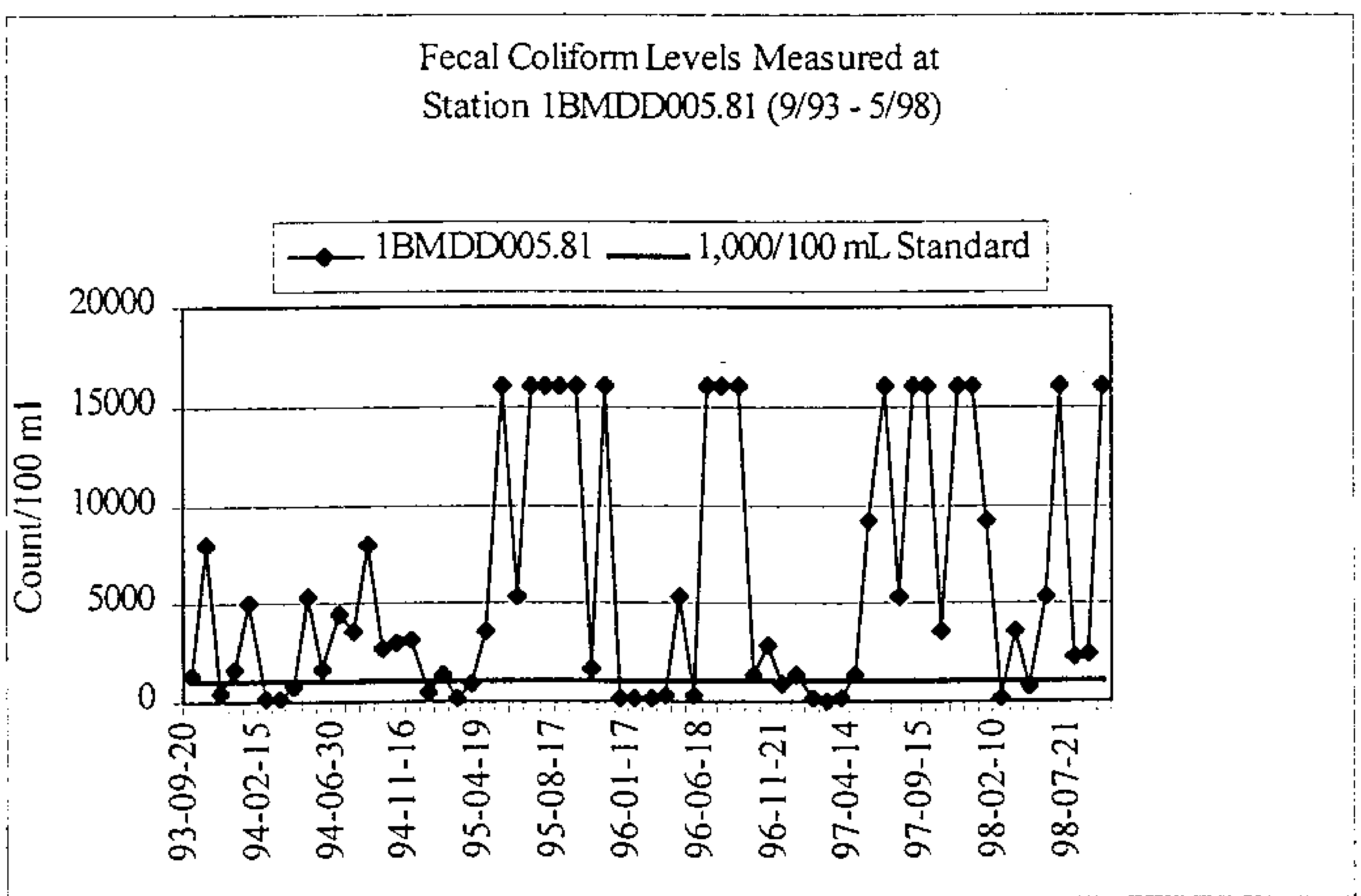


Figure 2.6. Observed fecal coliform concentrations at station 1BMDD005.81

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3.0 SOURCE ASSESSMENT

The TMDL evaluation summarized in this report examined all potential sources of fecal coliform in the Muddy Creek watershed. The source assessment was used as the basis of development of the model and ultimate analysis of the TMDL allocation options. In evaluation of the sources, loads are characterized by the best available information, monitoring data, literature values, and local management activities. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and nonpoint sections. The representation of the following sources in the model is discussed in Section 4.0, *Modeling Procedure: Linking the Sources to the Endpoint.*

3.1 Assessment of Point Sources

The greatest potential source of human fecal coliform from point sources is raw sewage. Raw sewage typically has a total coliform count of 10^5 to 10^9 counts/100 ml (Novotny and Olem, 1994; Metcalf & Eddy, 1991) and a fecal coliform count of 10^6 to 10^8 counts/100 ml (Metcalf & Eddy, 1991) along with significant numbers of viruses, protozoans, and other parasites. Typical treatment in a municipal plant reduces the total coliform count in effluent by about 3 orders of magnitude, to the range of 10^4 to 10^6 counts/100 ml. Raw sewage, although not usually discharged intentionally, can reach waterbodies through leaks in sanitary sewer systems, overflows from surcharged sanitary sewers (noncombined sewers), illicit connections of sanitary sewers to storm sewer collection systems, or unidentified broken sanitary sewer lines.

Two point sources are known to discharge to Muddy Creek—the Wampler Foods, Inc. wastewater treatment facility at Hinton (river mile 3.7) and the Mount Clinton Elementary School at Mount Clinton (Figure 3.1). Wampler Foods is a poultry slaughtering and processing facility, and the Mount Clinton School stabilization lagoon which has never discharged to Muddy Creek. (VADEQ, 1997). Both point sources have a Virginia Pollutant Discharge Elimination System (VPDES) permit. Table 3.1 lists the point source dischargers and permit information, and Figure 3.1 shows their discharge locations. Names and locations of the dischargers in the watershed were obtained from the Permit Compliance System (PCS) database.

Wampler's wastewater treatment facility treats process waste, cafeteria waste, process waste cleanup, boiler blow down, truck cleaning, and storm water. Sanitary waste is treated separately and is chlorinated prior to discharge. Stormwater from the facility during small storms and the first flush of large storms is routed to a lagoon. The stormwater from the lagoon is treated before discharge. All of Wampler's treated waste is discharged through outfall 001. Outfalls 101 and 901 are internal and discharges are routed through outfall 001. The secondary outfalls (002 and 003) are activated to handle excess stormwater during extreme storm events. Water discharged from these secondary outfalls would occur after the first flush had gone to the lagoon for treatment. Therefore the occasional discharge from the secondary outfalls does not have a significant impact on fecal coliform bacteria levels in the Muddy Creek basin. Outfalls 001, 002, 003, 101, and 901 and the number of monitoring observations are shown in Table 3.2. A summary of average monthly discharge, average monthly fecal coliform counts, and maximum monthly fecal coliform counts for the outfall 001 is shown in Table 3.3.

Since the Mount Clinton Elementary School has not discharged to a surface water source, VADEQ deemed its impact on the water quality negligible (VADEQ, 1997). The school is scheduled to close in the near future.

Figure 3.1 Point Source Dischargers within the Muddy Creek Watershed

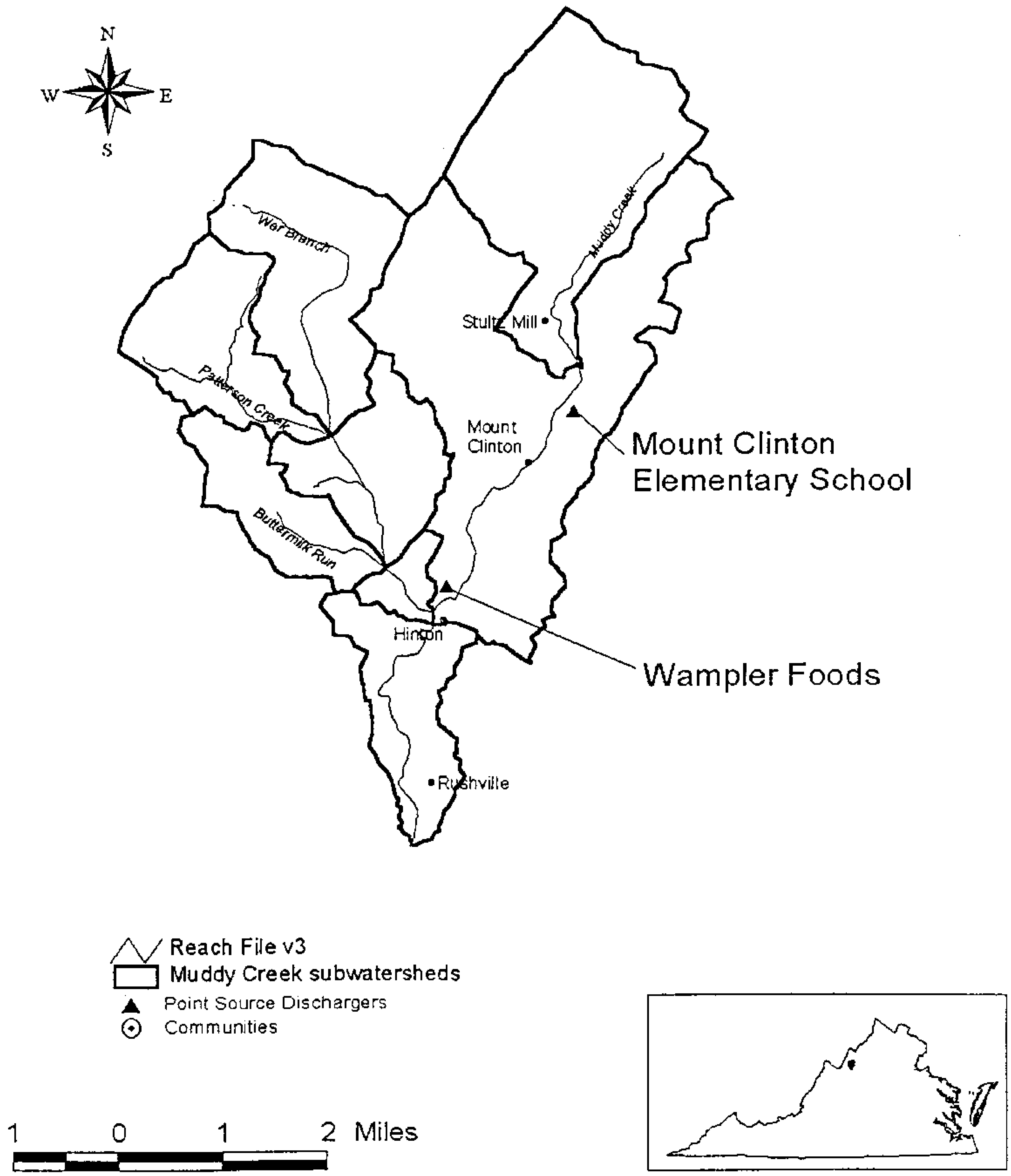

Table 3.1. VPDES permitted dischargers in the Muddy Creek watershed

VPDES No.	Facility name	Fecal coliform permit limit (counts/100 ml)	
		Average Monthly	Instantaneous Maximum
VA0002313	Wampler Foods, Inc. - Hinton	200 [1]	400
VA0062928[2]	Mount Clinton Elementary School	n/a	n/a

[1] Monthly average is reported as a geometric mean.
[2] Has not discharged to surface water and considered unnecessary for analysis due to scheduled closure.

Table 3.2. Wampler Foods wastewater treatment facility (VA0002313) discharge characterization

Outfall	001	002	003	101	901
Period	2/90 to 8/98	Intermittent	Intermittent	4/96	12/97
No. of observations	103	12	5	1	1

Table 3.3. Discharge characterization of outfall 001 of Wampler Foods wastewater treatment facility

	Flow Avg Monthly (ft^3/s)	Fecal Coliform (Counts/100mL)	
		Avg Monthly	Max Monthly
No. of observations	103	100	102
Average	0.483	3.519	44.419
Median	0.493	1.90	6.00
Minimum	0.317	1.00	0.90
Maximum	0.622	54.8	2400

3.2 Assessment of Nonpoint Sources

Nonpoint sources of fecal coliform bacteria are typically separated into urban and rural components. In urban or residential settings with high amounts of paved impervious area, important sources of loading are surface stormwater flow, failing septic tanks, and leakage of sanitary sewer systems. In rural settings, the amount of impervious area is usually much lower, and sources of fecal coliform may include runoff of animal wastes associated with the erosion of sediments, runoff from concentrated animal operations, contributions from wildlife, and failing septic tanks.

To spatially analyze the bacteria loading for purposes of modelling, the Muddy Creek watershed was divided into eight subwatersheds (Figure 3.2). The land uses in each of the subwatersheds were determined using data provided by the Virginia Department of Conservation and Recreation (VADCR). VADCR used 1990 Rockingham Digital Ortho Quarter Quad (DOQQ) orthophotographs for field boundaries and used 1989 and 1991 National Aerial Photography Program (NAPP) and 1992 and 1994 Farm Service Agency (FSA) aerial slides for the land use classification process. A total of 24 of the VADCR land use categories, not including the "water" classification, were identified in the Muddy Creek watershed. These 24 land use categories were aggregated into 9 land use categories for this study. Table 3.4 shows the VADCR land use categories and the aggregated categories and also indicates the percent pervious and impervious for each of the land use classes. Table 3.5 presents the land use distribution throughout the Muddy Creek watershed and its eight subwatersheds. Appendix A contains a detailed land use distribution including Virginia classifications and the grouped categories used in this study.

Each land use has various nonpoint sources that contribute fecal coliform to the land surface. The fecal coliform is then available for washoff to the receiving waters of the watershed. The nonpoint sources discussed in this section are represented in the model for each land use they affect, accounting for their contribution of fecal coliform to Muddy Creek. The sources were evaluated and the associated fecal coliform accumulation rates were determined. The nonpoint sources discussed in this section include

- Failing septic systems and other uncontrolled discharges
- Wildlife
- Land application of liquid dairy manure
- Land application of poultry litter
- Cattle contributions directly deposited instream
- Grazing animals

Figure 3.2
Muddy Creek Subwatersheds

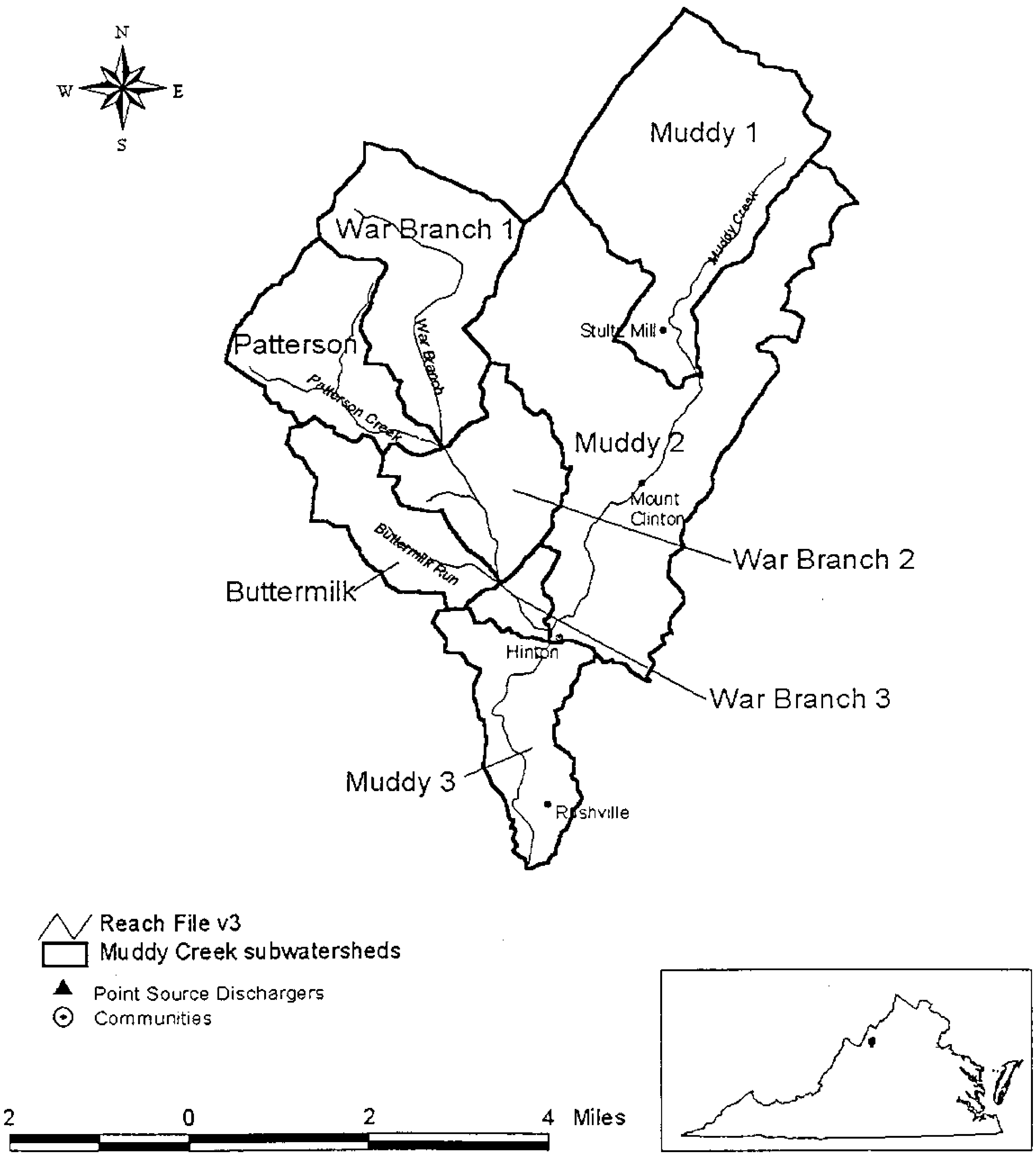

Table 3.4. Muddy Creek Watershed Land Use Category Groupings

TMDL Land Use Categories	Pervious/Impervious (Percentage)[1]	VADCR Land Use Categories (Class No.)
Cropland	Pervious (100%)	Row Crop (2110) Gullied Row Crop ((2111) Row Crop Stripped (2113) Rotational Hay (2114) Orchard (221)
Pasture 1	Pervious (100%)	Improved Pasture/Hayfield (2122)
Pasture 2	Pervious (100%)	Unimproved Pasture (2123) Grazed Woodland (43)
Pasture 3	Pervious (100%)	Overgrazed Pasture (2124)
Farmstead	Pervious (72%) Impervious (28%)	Housed Poultry (2321) Farmstead (13) Farmstead with Dairy Waste Facilities (813) Large Individual Dairy Waste Facilities (8)
Built-up	Pervious (75%) Impervious (25%)	Built-up <50% porous (11) Built-up >50% porous (12) Wooded Residential (44) Rural Residential (14) Unclassified (999)
Loafing Lots	Pervious (100%)	Dairy Loafing Lots (2312) Unhoused Poultry (2322)
Forest	Pervious (100%)	Forest Land (40)
Barren	Pervious (100%)	Recently Harvested Woodland -clear cut (41) Recently Harvested Woodland - not clear-cut (42) Transitional/Disturbed Sites (7)

[1]Land uses are classified with pervious and impervious components in the model.

Table 3.5. Land use distributions in the Muddy Creek watershed (units in acres)

Land use	Muddy3	Muddy2	War3	War2	Buttermilk	War1	Muddy1	Patterson	Total
Cropland	716.17	2249.07	122.78	767.77	280.87	70.04	913.79	31.05	5151.54
Pasture1	457.04	1954.36	142.27	442.81	407.82	98.96	1141.89	38.2	4683.35
Pasture2	14.93	123.31	8.83	32.72	28.39	10.27	48.49	23.39	290.33
Pasture3	60.71	446.91	0.0	112.71	96.5	95.1	219.77	1.97	1033.67
Farmstead	152	344.19	29.86	128.21	42.28	12.5	161.42	4.08	874.54
Built-up	35.1	354.48	61.56	32.77	99.88	97.33	269.21	7.36	957.69
Loafing	50.59	53.44	3.56	22.09	15.8	0.0	13.57	0.0	159.05
Forest	105.55	992.5	0.0	81.39	350.19	2,300.99	1,303.16	1730.13	6863.91
Barren	0.0	0.0	0.0	0.0	2.39	0.0	0.0	7.73	10.12
Total	1,592.09	6,518.26	368.86	1,620.47	1,324.12	2,685.19	4,071.3	1,843.91	20024.2

3.2.1 Failing Septic Systems and Uncontrolled Discharges

Onsite septic systems provide the potential to deliver bacteria loads to surface waters due to system failure to provide adequate treatment due to malfunctions. No information was available on the specific locations of septic systems, septic tank densities, or failure rates. Therefore, inputs from failed septic systems have not been linked to any particular land use category(ies). However, VADCR provided numbers for septic systems in the watershed, based on US census data, indicating that there are 1,145 septic systems within the Muddy Creek watershed serving an estimated population of 3,194. A septic system failure rate of 2.5% was estimated for Rockingham County (NSFC, 1993) and used to estimate the number of failing septic systems in the county. The number of failing septic systems in each subwatershed was then estimated proportionally based on land area (Table 3.6). In representing the fecal coliform contribution from failing septic systems, it was also assumed that 100 percent of the fecal coliform load reached the receiving waters at a concentration of 10^4 counts/100 ml (Horsley & Witten, 1996). The 10^4 counts/100 ml concentration is the low end of a range of typical values of fecal coliform concentration for septic effluent (Horsley & Witten, 1996). The low end was chosen to account for die-off of bacteria during transport to receiving water. The assumed septic system waste flow was based on a typical value of 70 gallons per capita per day (Horsley & Whitten, 1996) and an average of 2.8 persons per household, calculated from number of septic systems and population served in the watershed.

In addition to failing septic systems, straight pipes, and other uncontrolled discharges (sinkhole dumps, sinkhole "wash-in", dairy parlor waste) may also contribute fecal coliform loads to receiving waterbodies. There is no information available on the number and location of straight pipes or dairy parlor waste discharges, and only limited, incomplete information available for sinkholes. Because fecal contributions from these sources can be highly variable, depending on source concentration, presence/absence of soil interception, etc., uncontrolled discharges were approximated using calculations for a "typical" straight pipe source (see Section 4.3.1). It was assumed that three uncontrolled discharges contribute fecal coliform directly to the stream in both Muddy 2 and War 2, resulting in a total of six "uncontrolled discharges" in the watershed. As with septic systems, uncontrolled discharges were not linked with any particular land use category.

Table 3.6. Input of failing septic systems and uncontrolled discharges estimated in the Muddy Creek watershed

Subwatershed	Total area (acres)	Failing septic systems	Uncontrolled discharges
Muddy 3	1,592.09	2	0
Muddy 2	6,518.26	9	3
War 3	368.86	1	0
War 2	1,620.47	2	3
Buttermilk	1,324.12	2	0
War 1	2,685.19	4	0
Muddy 1	4,071.3	6	0
Patterson	1,843.91	3	0
TOTAL	**20,024.2**	**29**	**6**

3.2.2 Wildlife

VADCR provided a deer density, obtained from Virginia Department of Game and Inland Fisheries, of 35 deer per square mile (mi^2) of deer habitat (email from Mark Bennett, VADCR, 8/12/98). Deer habitat includes the Forest, Cropland, Pasture 1, Pasture 2, Pasture 3, Built-up and Barren land classes. Using the provided deer density and the areas of deer habitat available in the watershed, the total estimated number of deer in the watershed is calculated at 1,038. Deer counts are listed in Table 3.7. The deer population estimates were used to calculate the potential fecal coliform loading from wildlife.

Table 3.7. Distribution of deer in Muddy Creek watershed

Subwatershed	Total Area (acres)	Total Area of Deer Habitat (acres)	Deer
Muddy 3 (22)	1,592.09	1,389.5	76
Muddy 2 (23)	6,518.26	6,120.63	335
War 3 (24)	368.86	335.44	18
War 2 (25)	1,620.47	1,470.17	80
Buttermilk (26)	1,324.12	1,266.04	69
War 1 (27)	2,685.19	2,672.69	146
Muddy 1 (28)	4,071.3	3,896.31	213
Patterson (29)	1,843.91	1,839.83	101
TOTAL	**20,024.2**	**18,990.61**	**1,038**

3.2.3 Land Application of Liquid Dairy Manure

Waste from dairy cows is applied to agricultural land within the watershed and represents a potential source of significant fecal coliform loading to receiving waterbodies. Liquid dairy manure is applied to cropland at a rate of 6,600 gallon/acre/year and to hayland at a rate of 3,900 gallon/acre/year (email from Mark Bennett, VADCR, 7/30/98). (Hayland is represented as "Pasture 1" in this study.) The portion of land receiving liquid dairy manure was determined based on the assumption that all liquid dairy manure produced in the watershed is used for application within the watershed. To determine the portion of land receiving liquid dairy manure application, the total amount of liquid dairy manure produced in the watershed was calculated (gal/year) and the percentages were determined by the following equation (assuming that the portion of hayland acres and the portion of cropland acres receiving manure are the same):

*(x% * cropland acres * 6600 gal/acre/yr) + (x% * hayland acres * 3900 gal/acre/yr) = gal/yr produced*

The total amount of manure produced per year was calculated using the number of dairy cows in the watershed, the amount of liquid dairy manure produced by a cow during a full day while confined, and the amount of time cows are confined. Assuming there are 6,533 dairy cows in the watershed and a cow produces an estimated 17 gallons of liquid manure per full day while confined and, according to monthly confinement information provided by VADCR field staff, spend approximately 179 days confined during a year, solving the equation indicates that approximately 38 percent of cropland and hayland acres receive liquid dairy manure.

3.2.4 Land Application of Poultry Litter

Poultry litter is applied to agricultural land within the Muddy Creek watershed. Accumulated on the land and available for runoff during wet weather, litter represents a potentially significant source of fecal coliform loading to Muddy Creek and its tributaries. Total poultry numbers and accompanying litter production (in tons) for the watershed are: 50,098 chickens/751 tons; 508,325 broilers/3966 tons; and 351,336 turkeys/17,565 tons. Total tons of litter were calculated by multiplying the numbers of birds per cycle times the number of cycles per year times the litter production per bird in a cycle. Poultry litter is applied to Cropland, Pasture 1, Pasture 2, and Pasture 3. Table 3.8 presents information on application rates and land receiving application (as provided by VADCR). The total amount of litter produced within the watershed was calculated based on estimates provided by VADCR and SWCD, and compared to the amount applied. Assuming that all litter produced within the watershed is applied in the watershed and based on mass balance of the application rates and acreages for cropland and pasture versus the total litter produced, the portion of pasturelands (1, 2, and 3) receiving litter application is computed to be 80 percent, so that the amount of litter applied does not exceed the amount produced. Based on information from VADCR and Soil and Water Conservation District (SWCD) field staff, it is assumed that litter is applied to only that portion of cropland that does not receive liquid dairy manure. As calculated for mass balance and confirmed by field staff estimates, it is also assumed that 18% of Pasture 1 lands receive applications of both poultry litter and dairy manure, with the application rates and amounts applied varying by month.

Table 3.8. Poultry litter application information for the Muddy Creek watershed

Land use	Application rate (ton/acre/year)	% of land receiving application
Cropland	3	62
Pasture 1	3	80
Pasture 2	1.5	80
Pasture 3	1.5	80

3.2.5 Cattle Contributions Directly Deposited Instream

Total numbers of beef (3,134) and dairy (6,533) cattle in the watershed were obtained from the VADCR Hydrologic Unit Planning (HUP) database. These numbers are based on agricultural census information, confirmed by SWCD, DCR, VCE, and NRCS representatives in the county.

A small proportion of cattle are excluded from the streams within the Muddy Creek watershed (email from Mark Bennett, VADCR, 11/2/98). VADCR provided a methodology for determining the number of cows in the stream under current conditions. This methodology is intended to duplicate field staff observations and estimates from the watershed. It was assumed that 90 percent of the cows grazing on pastureland between 0 and 5 percent slope have access to the stream and that 65 percent of cows grazing on pasture land with slopes greater than 5 percent have access to the stream. VADCR provided estimates of the amount of time the cows with access to the stream spend actually in the stream. Land areas in the Muddy Creek watershed of slopes greater and less than 5 percent were determined using a geographic information system (GIS) coverage of slopes in Muddy Creek overlain on the land use coverage. The area of pasture having slopes between 0 and 5 percent was determined as a total for all pasture lands (i.e., Pasture 1, Pasture 2, and Pasture 3). Acreages were not separated for each individual category. The total area of Pastures 1,2, and 3 having percent slope between 0 and 5 is 1,076.13 acres, approximately 18 percent of the total land area of pasture. Of the total grazing cows in the watershed each month, the number of dairy cows and beef cows with access to the streams during each month were determined by using those land areas. Cows with access to the stream spend one-sixth (17 percent) of their time in the stream during March and November; one-third (33 percent) of their time in April, May, September, and October; and one-half (50 percent) of their time in June, July, and August. These times were used to estimate the amount of time the cows spent "in and around" the stream during each month. The effective number of cows assumed to be depositing waste in the stream was assumed to be 30 percent of the cows "in and around" the stream. (Because dairy cows are confined during the winter months, the number of cows with access to the stream varies monthly, as does the number in the stream. Numbers of cows confined in winter are based on DCR field staff estimates.) The number of cows considered to be in the stream during each month is presented in Table 3.9.

Table 3.9. Monthly numbers of cows in the streams of Muddy Creek watershed

Month	Beef Cows in the Stream	Dairy Cows in the Stream
Jan	2	0
Feb	2	0
Mar	109	136
Apr	217	317
May	217	317
Jun	326	476
Jul	326	476
Aug	326	476
Sep	217	317
Oct	217	317
Nov	109	136
Dec	2	0

3.2.6 Grazing Animals

Grazing cattle and other agricultural animals deposit manure and, therefore, fecal coliform on the land surface, where it is available for washoff and delivery to receiving waterbodies. Grazing animals in the Muddy Creek watershed contribute fecal accumulation to the pasturelands (Pastures 1, 2, and 3) and the loafing lots.

Beef cattle not in the stream are assumed to graze in Pasture 1, Pasture 2, and Pasture 3. Descriptions of Virginia land use classes indicated that animal traffic is the lowest in Pasture 1 and the highest in Pasture 3. For this reason, it was assumed that 40 percent of the cattle graze in Pasture 1, 10 percent in Pasture 2, and 50 percent in Pasture 3, resulting in a the highest cattle density in Pasture 3 and the lowest in Pasture 2 (with density equal to number of cattle per acre) Due to the monthly variation of cattle in the stream, total number of beef cattle grazing in the pasturelands also varies by month. For each month, cattle grazing on the land (total cows minus cows in stream) were distributed throughout Pasture 1, Pasture 2, and Pasture 3 based on the distribution percentages (i.e., 40 percent in Pasture 1, etc.) and were then distributed proportionally throughout the eight subwatersheds based on land area. Table 3.10 presents the number of beef cattle in the stream and grazing on each pastureland during each month.

Table 3.10. Monthly distribution of beef cows throughout stream and pasture lands.

Month	# Beef cows in Pasture 1	# Beef cows in Pasture 2	# Beef cows in Pasture 3	# Beef cows in stream	Total beef cows
Jan	1,253	313	1,566	2	3,132
Feb	1,253	313	1,566	2	3,132
Mar	1,210	303	1,512	109	3,025
Apr	1,167	292	1,458	217	2,917
May	1,167	292	1,458	217	2,917
Jun	1,123	281	1,404	326	2,808
Jul	1,123	281	1,404	326	2,808
Aug	1,123	281	1,404	326	2,808
Sep	1,167	292	1,458	217	2,917
Oct	1,167	292	1,458	217	2,917
Nov	1,210	303	1,512	109	3,025
Dec	1,253	313	1,566	2	3,132

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Sheep also graze in the Muddy Creek watershed. Assuming that Pasture 3 receives more animal traffic, the sheep were distributed throughout the Pasture 3 land in the watershed. VADCR provided total sheep counts in the watershed, and they were distributed throughout the subwatersheds proportionally based on Pasture 3 land use. The sheep spend all of their time in the pasture, resulting in consistent numbers throughout the year. Table 3.12 contains the distribution of sheep throughout the watershed.

The majority of the poultry birds in the Muddy Creek watershed are confined in poultry houses; however, a portion of the turkeys in the watershed are not confined. These range turkeys contribute manure and fecal coliform to the land surface, representing another source of fecal coliform loading in the watershed. However, given the small area of land used for range turkeys and the relatively small number of range turkeys, they are a minimal contributor of fecal coliform loading in the Muddy Creek watershed. VADCR provided the total number of turkeys in the watershed and a method of determining the unhoused portion. Range poultry was identified as a land use in the watershed from aerial photographs. Using an estimated density of 775 turkeys/acre, the turkeys were distributed throughout the "Range poultry" land of the Loafing Lots land use category (Table 3.13). The total number of range poultry was then subtracted from the total number of turkeys in the watershed. The remaining 343,970 turkeys are confined in poultry houses, providing no fecal coliform contribution directly to the land surface.

Table 3.12. Distribution of sheep throughout Muddy Creek watershed

Subwatershed	# of sheep (all on Pasture 3)
Muddy 3	77
Muddy 2	566
War 3	0
War 2	143
Buttermilk	122
War 1	120
Muddy 1	278
Patterson	2
TOTAL	1,311

Table 3.13. Distribution of range turkeys throughout Muddy Creek watershed

Subwatershed	Number of range turkeys
Muddy 3	0
Muddy 2	6,468
War 3	0
War 2	0
Buttermilk	0
War 1	0
Muddy 1	1,898
Patterson	0
TOTAL	8,366

Information provided by VADCR field staff indicates 224 hogs present in the watershed. These hogs are all housed and , therefore, do not contribute any fecal coliform loadings to the watershed.

4.0 MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between the in-stream water quality target and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired source load reductions. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses to flow and loading conditions. In this section, the selection of the modeling tools, setup, and model application are discussed.

4.1 Modeling Framework Selection

The U.S. EPA Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) system Version 2.0 (USEPA, 1998) and the Nonpoint Source Model (NPSM) were used to predict the significance of fecal coliform sources and fecal coliform levels in the Muddy Creek watershed. BASINS is a multipurpose environmental analysis system for use in performing watershed and water quality-based studies. A geographic information system (GIS) provides the integrating framework for BASINS and allows for the display and analysis of a wide variety of landscape information (e.g., land uses, monitoring stations, point source dischargers). The NPSM model simulates nonpoint source runoff from selected watersheds, as well as the transport and flow of the pollutants through stream reaches. Several key reasons for using BASINS as the modeling framework are its ability to integrate both point and nonpoint source simulation, its ability to assess in-stream water quality response, and its ability to simulate seasonal variations and critical flows.

4.2 Model Setup

To obtain a spatial variation of the concentration of bacteria along Muddy Creek, the watershed was subdivided into eight subwatersheds in an effort to isolate the major stream reaches in the Muddy Creek watershed. This allowed analysts to address the relative contribution of sources within each subwatershed to the different segments of the river. The delineation of the eight subwatersheds was based primarily on a topographic analysis of the Muddy Creek watershed, with delineation along topographic drainage divides.

4.3 Source Representation

Both point and nonpoint sources were represented in the model. Of the point sources located in the watershed, only the Wampler Foods facility was included in the model. Because the Mount Clinton School has never discharged and because it is scheduled to close at the end of the current school year, it was not included in the in the model. VADEQ provided monthly effluent concentrations for the Wampler facility that included flow rates and fecal coliform concentrations. Using values reported in effluent monitoring data, maximum flow and fecal coliform concentrations (maximum observed value for geometric mean) were calculated for

Wampler, as indicated in Table 4.1 and Tables 3.1, 3.2, and 3.3. The use of maximum observed values provides a more conservative approach to load estimation.

Table 4.1. Model input parameters for point sources in the Muddy Creek watershed

Point source discharger	Fecal coliform rate	Flow rate
Wampler Foods	3.5×10^7 counts/hour	0.62 ft^3/s

The nonpoint sources discussed in Section 3.2 are represented in the model to account for their contribution to fecal coliform loading to Muddy Creek. Fecal coliform accumulation rates (counts /acre/day) were calculated for each land use based on all sources contributing fecal coliform to the surface of the land use. For example, the fecal coliform accumulation rate for cropland is the sum of accumulation rates due to liquid dairy manure application, litter application, and deer. Accumulation rates for Cropland, Pasture 1, Pasture 2, Pasture 3, and Loafing Lots were calculated on a monthly basis to account for seasonal variations in litter and liquid dairy manure application and grazing schedules. Table 4.2 contains typical fecal coliform production rates (in counts per day) and the fecal coliform content of feces (in counts per gram) for various animals. The production rates and the contents of feces were used to calculate fecal coliform contributions from various sources, as discussed in the following sections. After accumulation parameters were calculated for each land use, an exponential die-off function was then applied to the calculated maximum accumulation rates. The die-off is represented by the following equation (Horsley and Witten, 1996):

$$N_t = N_0 \,(10^{-kt})$$

where:

N_t = number of fecal coliform at time t (available for entrainment by surface runoff)
N_0 = number of fecal coliform at time 0
t = time in days
k = first order die-off rate constant

The value used for k = 0.51 (Moore, et al., 1982; Horsley and Witten, 1996)

Although potential regrowth of bacteria in stream sediment is recognized as a possible factor in this watershed, insufficient field and research information was available to model potential regrowth. Additionally, the VADEQ water quality sweep (Chapter 2) suggests that resuspension of sediment (by storm turbulence, animals walking in streams, etc.) may influence instream coliform counts. However, this factor is not understood sufficiently to be addressed in the modelling. Both factors should be considered for further research in conducting TMDL studies of Virginia's fecal coliform impaired waters.

Table 4.2. Fecal coliform production rates and fecal content for various animals.

Animal	Fecal Coliform Production Rate	Fecal Coliform Content of Feces	Reference
Cow	5.4×10^9 cfu/day	0.23×10^6 cfu/g	Metcalf & Eddy, 1991
Chicken	0.24×10^9 cfu/day	1.7×10^4 cfu/g[1]	Metcalf & Eddy, 1991; NCSU, 1990
Turkey	0.13×10^9 cfu/day	0.29×10^6 cfu/g	Metcalf & Eddy, 1991
Sheep	1.8×10^{10} cfu/day	1.6×10^7 cfu/g	LIRPB, 1982
Deer	0.50×10^9 cfu/day	N/A	Linear interpolation; Metcalf & Eddy, 1991

[1] Fecal coliform content of litter.

4.3.1 Failing Septic Systems and Uncontrolled Discharges

Septic system discharges were quantified based on the following information: the number of septic systems in the Muddy Creek watershed, the estimated population served by the septic systems, an assumed failure rate of 2.5 percent, an average daily discharge of 70 gallons/person/day (Horsley & Whitten, 1996), and a septic effluent concentration of 10^4 counts/100 mL (Horsley & Whitten, 1996). The concentration was selected based on the likelihood that only a portion of the bacteria contributed by a failed septic system will reach the stream, with some bacteria being intercepted by soil. Additionally, these septic system discharges are assumed to be constant throughout the year, while in reality septic system failures may occur only at certain times a year during periods of high precipitation and high water tables.

In representing straight pipes and other uncontrolled discharges such as sinkholes and milking parlor washoff in the model, it was assumed that there are a total of six discharges in the watershed, three each in Muddy 2 and War 2. As explained in Section 3.2.1, each uncontrolled discharge is approximated by a straight pipe from single household family of 2.8 people. The discharges are represented as discharging directly to the stream at a constant rate, with an assumed discharge rate of 70 gal/day/person (Horsley & Whitten 1996) and effluent concentration of 5×10^6 counts/100 mL (Metcalf & Eddy 1991). Because of the assumption of direct discharge to a stream, with no soil interception, the fecal concentration used is higher than that for failed septic systems.

4.3.2 Wildlife

Deer were distributed throughout the watershed on Forest, Cropland, Pasture 1, Pasture 2, Pasture 3, Built-up, and Barren lands based on a density of 35 deer/mi^2, as discussed in Section 3.2. The fecal coliform accumulation rates were then determined using the fecal coliform production rate for deer (Table 4.2). Because there are no available literature values for fecal coliform production rates for deer, a value was estimated based on available information. The fecal coliform production rate for deer was assumed to be greater than that of a turkey but less than that of a cow, both rates which were available from the Metcalf & Eddy (1991) reference. The rate for deer was then determined by linear interpolation using the typical animal weights and their fecal coliform production rates. A cow was assumed to weigh 1400 lb, a turkey 25 lb, and a deer 125 lb. The "known" fecal coliform production rates for the cow and turkey are 5.4×10^9 and 0.13×10^9 counts/day, respectively. The interpolation method gives a rate of 0.5×10^9 counts/day for deer. When multiplied by the number of deer for a particular land classification, the result represents the maximum potential deposition/accumulation of fecal coliform due to deer for that land classification. Using this rate, fecal coliform accumulation due to deer waste was determined for Forest, Cropland, Pasture 1, Pasture 2, Pasture 3, Built-up, and Barren lands for use in NPSM. Because not all accumulated fecal coliform reaches the waterbody, the accumulation rate was input into the model, which them simulated surface buildup and washoff to produce loadings due to deer for each of these land use classes.

4.3.3 Land Application of Liquid Dairy Manure

Liquid dairy manure is applied to cropland and hayland in the Muddy Creek watershed, as discussed in Section 3.2. Application rates vary monthly, with application occurring during the spring and fall. Table 4.3 represents the yearly application schedule, including monthly application rates. It should be noted that only 38 percent of cropland and hayland receives liquid dairy manure application, as discussed in Section 3.2. However, because of limitations in the way that BASINS can accommodate manure distribution, for purposes of modelling the manure is actually distributed to 100% of the land use, and the rate is decreased proportionally.

Application of liquid dairy manure results in accumulation of fecal coliform on the land surface. Therefore, fecal coliform accumulation rates are directly influenced by and based on the application rates of liquid dairy manure. To determine fecal coliform accumulation factors for the model, it was necessary to determine the amount of fecal coliform present in the liquid dairy manure. Using the amount of dairy manure produced in one day (VADCR, 7/24/98) and the amount of fecal solids produced in one day (ASAE, 1998), the ratio of solid to liquid in the liquid dairy manure was calculated. The fecal coliform accumulation due to liquid dairy manure application was then determined using the fecal coliform content of fecal solids (Metcalf & Eddy, 1991), as listed in Table 4.2.

Table 4.3. Liquid dairy manure application schedule.

Month	% of Total Volume Applied	Hayland Application Rate (gal/acre)	Cropland Application Rate (gal/acre)
January	0 %	0	0
February	0 %	0	0
March	10 %	390	660
April	45 %	1755	2970
May	5 %	195	330
June	0 %	0	0
July	0 %	0	0
August	0 %	0	0
September	30 %	1170	1980
October	10 %	390	660
November	0 %	0	0
December	0 %	0	0

4.3.4 Land Application of Poultry Litter

Poultry litter is applied to the Cropland, Pasture 1, Pasture 2, and Pasture 3 land uses within the Muddy Creek watershed, as discussed in Section 3.2. Application rates vary monthly, with application occurring during the spring. Tables 4.4 and 4.5 present the yearly application schedule and rates for the land uses receiving litter application. It should be noted that, because only a portion of the lands receive litter application and the specific spatial distribution of application is not known, for purposes of modelling application rates were adjusted to represent the total amount applied distributed over 100 percent of the land, and the rate is decreased proportionally. For example, it is estimated that litter is applied to 62 percent of cropland at a rate of 3 ton/acre/year, which is equivalent to 1.86 ton/acre/year applied to 100 percent of cropland.

The monthly accumulation of litter on the land surface was determined for each land use on a monthly basis, accounting for percentages of land receiving application and monthly variations in application. The fecal coliform accumulation due to litter application was determined using the fecal coliform content of litter, as listed in Table 4.2.

Table 4.4. Litter application schedule for Cropland in the Muddy Creek watershed

Month	% of Total Amount Applied	% of Land Treated	Application Rate (ton/acre)
Jan	0	0	0
Feb	10	62.05	0.18
Mar	45	62.05	0.84
Apr	45	62.05	0.84
May	0	0	0
Jun	0	0	0
Jul	0	0	0
Aug	0	0	0
Sep	0	0	0
Oct	0	0	0
Nov	0	0	0
Dec	0	0	0
TOTAL	100	N/A	1.86

Table 4.5. Litter application schedule for pasture lands in the Muddy Creek watershed

	Pasture 1			Pasture 2 and 3		
Month	% of Total Amount Applied	% of Land Treated [a]	Application Rate (ton/acre)	% of Total Amount Applied	% of Land Treated [a]	Application Rate (ton/acre)
Jan	0	0	0	0	0	0
Feb	0	0	0	0	0	0
Mar	85	80	2.04	85	80	1.02
Apr	0	0	0	0	0	0
May	0	0	0	0	0	0
Jun	0	0	0	0	0	0
Jul	0	0	0	0	0	0
Aug	0	0	0	0	0	0
Sep	0	0	0	0	0	0
Oct	15	24	0.36	15	24	0.18
Nov	0	0	0	0	0	0
Dec	0	0	0	0	0	0
TOTAL	100	N/A	2.4	100	N/A	1.2

[a] Percentages account for the assumptions that 70% of farmers apply 1.5 tons/acre/year in March and 30% of farmers apply 0.75 tons/acre/year both in March and October (VADCR, 7/24/98) and that 80% of Pasture 1 receives application.

4.3.5 Cattle Contributions Directly Deposited Instream

The numbers of cows in the stream during each month was determined using the number of cows having access to the stream and information on the time spent in the stream, as discussed in Section 3.2. The instream cows were represented in the model as direct inputs of fecal coliform into the stream. Using the fecal coliform daily production rate of cows (Table 4.2), the daily contribution of fecal coliform to the stream for each cow was calculated and then totaled by subwatershed depending on the number of cows in the stream in that subwatershed. The instream cows were represented in the model as a point source input, with their total load delivered to the stream (counts/day) and the flow rate at which it is delivered (ft^3/s). Flow rate was determined using the amount of waste produced by a cow each day (lb/day) and an assumed density of the manure (lb/gal). Cattle in the stream are assumed to discharge at a constant rate. An assumed 30 percent loss of fecal coliform due to settling was represented in the modeling of fecal coliform contributions from cattle in the stream. This percentage was not modelled explicitly but was considered in developing allocations (e.g., for numbers of cows in streams).

4.3.6 Grazing Animals

Muddy Creek watershed contains various types of animals that contribute fecal coliform directly to the land surface during grazing. The most abundant animal is cattle, with beef and dairy cows grazing throughout the watershed, as discussed in Section 3.2. Beef cattle were distributed throughout Pasture 1, Pasture 2, and Pasture 3; dairy cattle were distributed throughout Pasture 1, Pasture 2, Pasture 3, and the Loafing Lots. Fecal coliform accumulation rates (counts/acre/day) for each of the land uses due to each of these animals were calculated using their distribution densities for each land use and their fecal coliform production rates as previously listed in Table 4.2. Fecal coliform accumulation rates (counts/acre/day) from turkeys were determined using number of turkeys and daily fecal coliform production rates (Table 4.2). Accumulation due to range turkeys were included in the accumulation rates for the Loafing Lots; however, because the range poultry land comprises such a small portion of the watershed, the range turkeys contribute a negligible accumulation compared to the dairy cows in the Loafing Lots. Sheep graze on Pasture 3 lands and contribute fecal coliform to the surface. As with the other animals, the accumulation rate from sheep was calculated based on number of sheep and the daily fecal coliform production rate, as listed in Table 4.2.

4.3.7 Background Conditions

Background conditions were included as loadings from forested land (detailed in subwatershed Forest Land load allocations in Appendix B) and a baseline background concentration of 30 counts/100 ml. Calculation of loadings from deer in forested lands is discussed in Section 4.3.2. The baseline concentration is set in the model and applies to all segments of the modelled stream network. The baseline concentration represents any natural background sources existing in the watershed (e.g., wildlife not specifically accounted for or inventoried in the analysis). Because there was no monitoring station in the area of Muddy Creek that drains a pristine watershed, the baseline concentration of 30 counts/100 ml was selected based on experience in water quality analyses of pristine watersheds. The value selected represents a conservative assumption. Values as low as and even lower than 30 counts/100 ml are observed in pristine watersheds.

Table 4.6. Annual fecal coliform loads from forested lands in each subwatershed of the Muddy Creek watershed.

Subwatershed	Annual fecal coliform loads from forested lands
Muddy 3	1.13E+09 counts/year
Muddy 2	1.06E+10 counts/year
War 3	0 counts/year
War 2	8.88E+08 counts/year
Buttermilk	3.82E+09 counts/year
War 1	2.45E+10 counts/year
Muddy 1	1.39E+10 counts/year
Patterson	1.85E+10 counts/year
TOTAL	7.33E+10 counts/year

4.4 Stream Characteristics

The channel geometry for the reaches in each Muddy Creek subwatershed were based on and interpolated from stream characteristics measured at three sites in the watershed (Muddy Creek, Mt. Clinton, 1993-96 records; Muddy Creek, Hinton, 1976-98; War Branch, Hinton, 1979-98) by the Water Resources Division of the State Water Control Board. Subwatershed segment lengths were determined using measurement tools within the BASINS modeling system. Table 4.7 contains the length, average depth, average width, maximum depth, and slope for each subwatershed reach.

Table 4.7. Stream geometry model inputs for the subwatersheds of Muddy Creek.

Subwatershed	Length (mile)	Average depth (ft)	Maximum depth (ft)	Average width (ft)	Slope
Muddy 3	3.57	0.8	1.2	15	0.002
Muddy 2	3.39	0.68	1.05	15	0.0025
War 3	0.89	0.6	0.9	15	0.0025
War 2	1.67	0.5	0.75	13	0.003
Buttermilk	1.60	0.5	0.75	13	0.004
War 1	3.44	0.4	0.6	9	0.006
Muddy 1	3.35	0.5	0.75	10	0.0045
Patterson	2.98	0.4	0.6	9	0.006

4.5 Selection of Representative Modeling Period

The hydrologic conditions in the Muddy Creek watershed are characterized by relatively random successions of dry, average, and wet rainfall years. A hydrologically representative time period used in modeling is necessary to account for the varying climatic and hydrologic conditions occurring within the watershed. During dry weather and low flow, constant direct discharges dominate the impact on instream concentrations; however, during wet weather and high flow periods, surface runoff delivers nonpoint source fecal coliform to the stream, affecting the instream conditions more than constant discharges. To represent the varying meteorological conditions within the Muddy Creek watershed, the representative modeling period used is 1991-1996. The 5-year period covers a range of climatic and hydrologic conditions within Muddy Creek, allowing for a more accurate analysis of source loading and instream conditions within the watershed.

4.6 Model Calibration Process

To develop a representative linkage between the sources and the instream water quality response in the eight reaches of the Muddy Creek watershed, model parameters were adjusted to the extent possible for both hydrology and bacteria loading. Hydrologic calibration required a comparison of the modeled stream flows for the portion of the watershed upstream from USGS gage 01621050 (Muddy Creek at Mount Clinton) to the observed flows, available for 4/13/93 to 9/30/96. Figure 4.1 shows the observed and modeled flows for the period of record. A variety of parameters relating to surface water runoff, water balance, and groundwater flows were adjusted within their reasonable range of values until the predicted flows adequately matched observed values. Some of these parameters represented groundwater storage, evapotranspiration, infiltration capacity of the soil, interflow inflow, and length of assumed overland flow. Based on this examination and a verification that the parameter values were reasonable, it was determined that the model adequately represents the hydrology of Muddy Creek. The model was also calibrated for water quality for the April 1993 to July 1996 time period to compare observed flow and water quality data for this time period to modelled conditions for the same time period. Once the model was calibrated for hydrology and water quality, it was run to determine existing loadings and allocation loadings for the representative time period of January 1991 through December 1995.

Fecal coliform accumulation and surface loading parameters for land uses were calculated based on contributions from various sources, as discussed in Section 4.3. After incorporating those model parameters and inputs, as well as contributions from point sources, septic systems, cows in the stream, and background concentrations in the reaches, the modeled instream fecal coliform concentrations were compared to available observed data. The modeled concentrations closely correspond to the observed values, as shown in Figure 4.2. The relative pattern of observed concentration levels is maintained in the modeled concentrations. It should be noted that the difference between the high fecal coliform observed values and the modeled high peaks is due to the methods of analysis for fecal coliform concentration. Analysis methods for fecal coliform data have maximum limits for detection, and the measured value of the sample may be significantly lower than the actual value. Different techniques were used to analyze water quality samples before and after February 1995, resulting in different maximum concentration values. Prior to February 1995 the maximum measurable concentration value was 8,000 counts/100 mL and after February 1995 was 16,000 counts/100 mL, as apparent in the observed data.

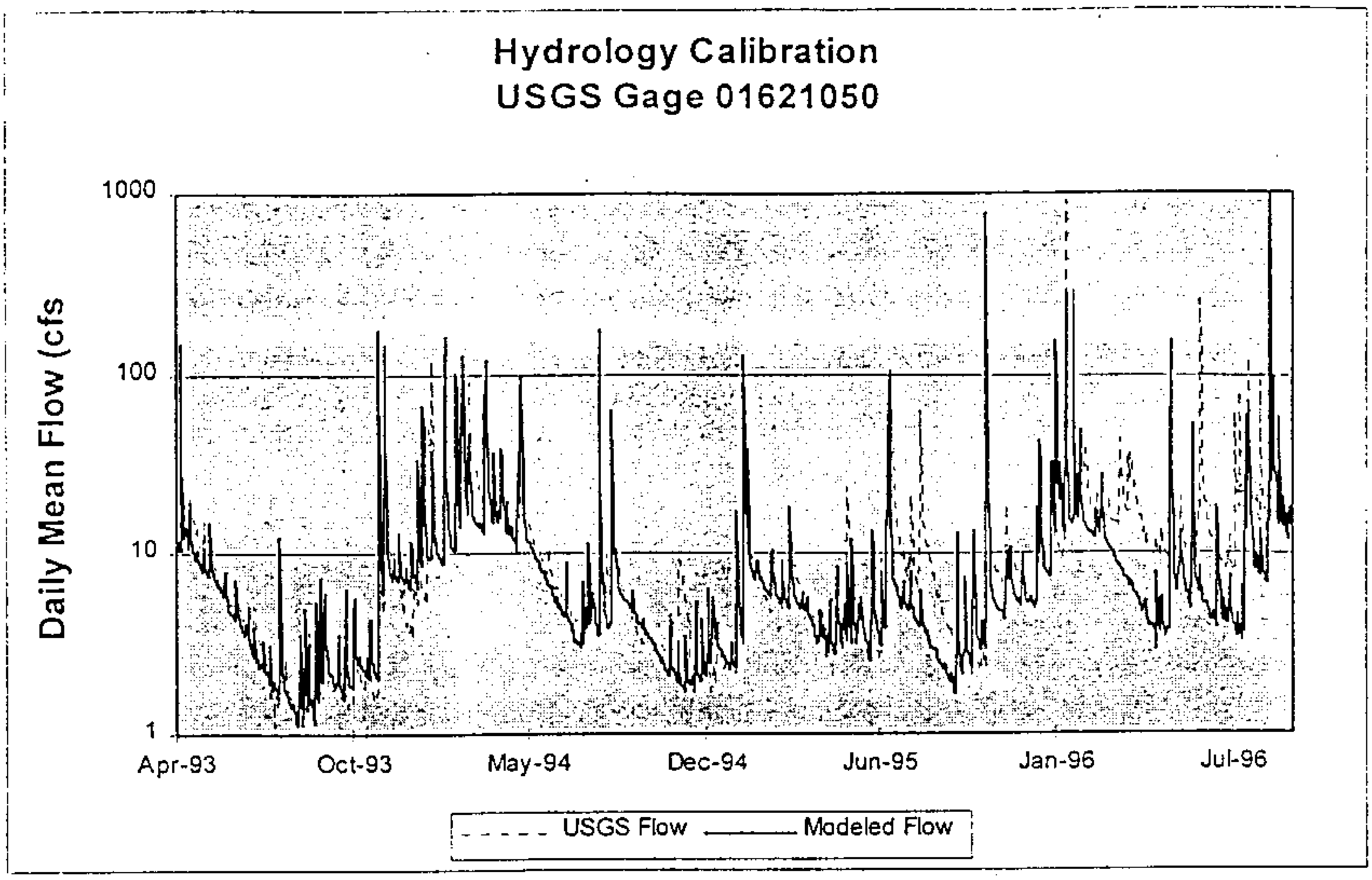

Figure 4.1. USGS observed flows and modeled flows for USGS gage 01621050.

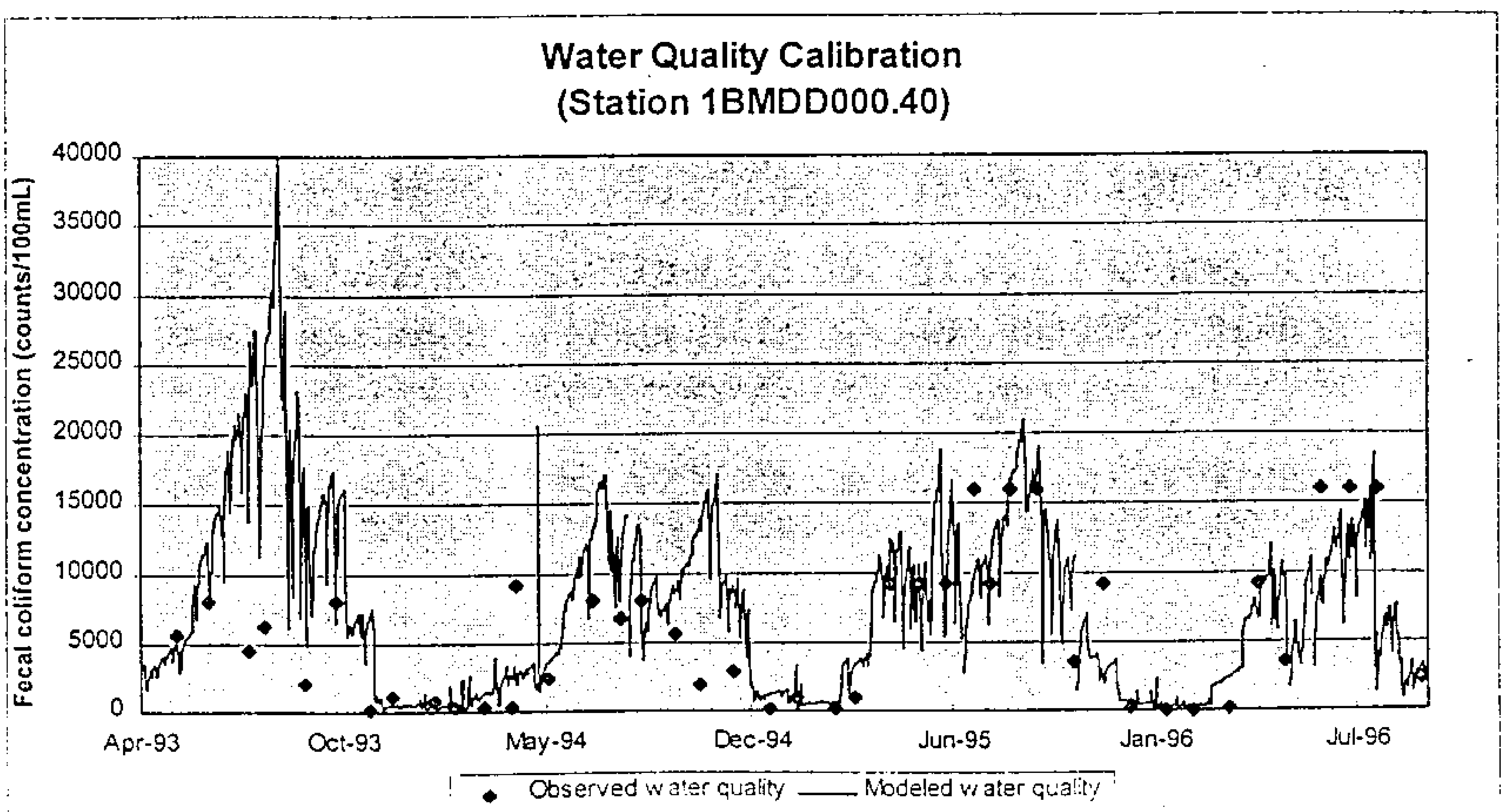

Figure 4.2. Modeled and observed fecal coliform concentrations at station 1BMDD000.40.

4.7 Existing Loadings

The model was run for the representative hydrologic period (January 1991 through December 1995). The modeling run represents the existing bacteria concentrations and loadings at various reaches of Muddy Creek. For the modeled existing conditions, the fecal coliform bacteria loadings by land use category for the entire Muddy Creek watershed are given in Table 4.8. (Refer to Section 4.3 for discussion of source contributions to each land use.) More specific fecal coliform loadings (e.g., monthly by subwatershed) are detailed in Appendix B. A summary of Virginia water quality standard violations for the selected representative hydrologic period is given in Table 4.9. It is apparent from Table 4.9 that modelling yields violations throughout the watershed with relative magnitude similar to those apparent in analysis of existing monitoring data.

Table 4.8. Annual nonpoint source fecal coliform loading for the entire Muddy Creek watershed under modeled existing conditions

Land use category	Annual fecal coliform loading (counts/year)
Builtup	1.88×10^{10}
Farmstead	1.78×10^{10}
Forest	7.33×10^{10}
Barren	1.32×10^{8}
Cropland	2.48×10^{11}
Loafing lots	4.11×10^{12}
Pasture 1	1.72×10^{12}
Pasture 2	2.19×10^{11}
Pasture 3	3.34×10^{12}

Table 4.9. Summary of violations of water quality standards (1,000 cfu/100 mL) under modeled existing conditions for representative hydrologic period (1/91 through 12/95).

Subwatershed	No. of exceedances	Max no. of days in an exceedance	Min no. of days in an exceedance	Total no. of exceedance days	Exceedance percentage
Muddy 3	41	277	1	1,439	78.85
Muddy 2	33	276	1	1,403	76.88
War 3	47	289	1	1,523	83.45
War 2	45	245	1	1,578	86.47
Buttermilk	34	274	1	1,362	74.63
War 1	25	190	1	1,061	58.14
Muddy 1	29	274	1	1,353	74.14
Patterson	26	148	2	759	41.59

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5.0 ALLOCATION

Total maximum daily loads (TMDLs) comprise the sum of individual waste load allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and natural background levels. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relation between pollutant loads and the quality of the receiving waterbody. Conceptually, this definition is denoted by the equation:

$$TMDL = \Sigma WLAs + \Sigma LAs + MOS$$

The TMDL is the total amount of a pollutant that can be assimilated by the receiving water while still achieving water quality standards.

For some pollutants, TMDLs are expressed on a mass loading basis (e.g., pounds per day). For bacteria, however, TMDLs can be expressed in terms of organism counts (or resulting concentration), in accordance with 40 CFR 130.2(i).

5.1 Sensitivity Analysis

Because the actual numbers of and contributions from straight pipes and uncontrolled sources (sinkhole dumps and wash-ins, dairy parlor discharges) are unknown, it was important to determine the relative impacts on water quality from variations in the loadings from these sources. Prior to the development of an allocation scenario designed to meet water quality standards, a sensitivity analysis of the model was performed for straight pipes and uncontrolled discharges.

The model was run for the following sensitivity scenarios: 1 straight pipe/uncontrolled discharge in each branch; 3 in each branch (inputs described in Section 4.3.1); and 1 in each subwatershed. Using one discharge per branch produced water quality output with no exceedances of the standard and was not comparable to existing monitored water quality conditions. Three discharges per branch produced a close match to the existing conditions of water quality violations, and increasing the number of discharges to one per subwatershed did not produce substantial increases in either the number or magnitude of violations and did not alter the pattern of water quality variations produced by the model.

Additionally for these sources, the impacts of potential removal of coliforms by soil (e.g., in sinkholes or in overland flow from dairy parlors) are poorly understood and constitute an uncertainty in modelling uncontrolled discharges. Sensitivity analyses simulating 0% efficiency and 80 % efficiency of removal showed no substantial differences in the number or magnitude of violations or the pattern of water quality variations produced by the model.

5.2 Incorporation of a Margin of Safety

The margin of safety (MOS) is part of the TMDL development process. There are two basic methods for incorporating the MOS (USEPA 1991a):

- Implicitly incorporate the MOS using conservative model assumptions to develop allocations or

- Explicitly specify a portion of the total TMDL as the MOS; use the remainder for allocations.

The allocation scenario for Muddy Creek was designed to meet the water quality standard of a geometric mean of 200 counts/100 mL with 0% exceedances. To provide an explicit 5% margin of safety, the modeled concentrations were compared to a target of a geometric mean (of 30 samples) of 190 counts/100 mL.

5.3 Scenario Development

TMDL development requires that the level of reduction from each pollutant source in a watershed be determined in order to meet the applicable water quality standard.

5.3.1 Wasteload Allocations

Point sources within the watershed discharging at their current level were considered negligible in their impact on instream fecal coliform levels. The allocations to point sources are equivalent to their existing loads, as listed in Table 5.1. It should be noted that Mt. Clinton Elementary School was not included in the model analysis because it has never discharged and is scheduled for closure. It therefore has an allocated load of 0 counts/day.

Table 5.1. Wasteload allocations to point sources in the Muddy Creek watershed

Point source	Existing load	Allocated load	Percent reduction
Wampler Foods, Inc.	8.34×10^8 counts/day	8.34×10^8 counts/day	0 %

5.3.2 Load Allocations

Discussion of load allocations to nonpoint sources is divided into categories of surface loadings from land uses, and direct discharges in the stream from: grazing animals, septic systems and uncontrolled discharges.

Using the model developed to represent existing conditions (see Sections 4.5 - 4.7), an allocation scenario was developed that would result in attainment of the water quality standard of a geometric mean of 200 counts/100 mL with a 5% margin of safety. For the allocation runs, the model was run for the same representative hydrologic period (1991 through 1995) as used for the calibration run for existing conditions.

The development of an allocation scenario is an iterative process that requires multiple model runs. Source reductions are simulated in the model and their impact is assessed against the water quality target. Additional reductions are added until the water quality standard is met. Scenarios developed in the various model runs also examine combinations of reductions which could realistically be implemented.

Source reductions can be divided into two groups: those that affect low flow, and those that effect loadings during rainfall events. To meet the water quality standard in Muddy Creek, reductions from sources that effect both low flow and rainfall events were needed. To meet the water quality target, reductions from sources that impact low flow in Muddy Creek needed to be very high on a percent basis because of high loadings in a low flow volume.

Table 5.2 presents the overall nonpoint source loadings for fecal coliforms from each land use (for the total Muddy Creek watershed) for the existing condition and for the allocation scenario. The loadings shown in Table 5.2 are due to runoff during storm events. The left-hand column in the table indicates the land use; the second column is the average annual load from that land use in the existing condition; the third column is the average annual load from that land use after a source reduction is applied; and the right-hand column is the percent reduction needed from each land use to meet the water quality target. The allocation scenario indicates that an overall load reduction of 13 percent is needed from Cropland, 80 percent from Loafing Lots, 41 percent from Pasture 1, 42 percent from Pasture 2, and 42 percent from Pasture 3 lands in the Muddy Creek watershed for this TMDL. Because of the high potential for fecal coliform loading from unmanaged loafing lots, additional reductions of a few percent from loafing lots could substantially lower the reductions needed from the other land uses. The fecal coliform loadings from built-up, barren, forest and farmstead lands are an order of magnitude less than from the other land uses and no reductions were applied to them.

Table 5.2. Overall fecal coliform bacteria nonpoint source allocations for the Muddy Creek watershed for the representative hydrologic period

Land use	Total annual loading for existing run (counts/year)	Total annual loading for allocation run (counts/year)	Percent reduction
Built-up	1.88E+10	1.88E+10	0 %
Farmstead	1.78E+10	1.78E+10	0 %
Forest	7.33E+10	7.33E+10	0 %
Barren	1.32E+08	1.32E+08	0 %
Cropland	2.48E+11	2.16E+11	13.1 %
Loafing lots	4.11E+12	8.08E+11	80.3 %
Pasture 1	1.72E+12	1.01E+12	41.3 %
Pasture 2	2.19E+11	1.28E+11	41.8 %
Pasture 3	3.34E+12	1.94E+12	42.0 %
Total	9.75E+12	4.21E+12	56.8 %

Table 5.3. Load allocations to direct nonpoint sources of cows in the stream, failing septic systems, and uncontrolled discharges (for the entire Muddy Creek watershed)

Land use	Total annual loading for existing run (counts/year)	Total annual loading for allocation run (counts/year)	Percent reduction
Instream cattle	5.82E+14	4.14E+12	99.3 %
Failing septic systems	7.72E+11	0	100%
Uncontrolled Discharges	8.12E+13	0	100%
Total	6.64E+14	4.14E+12	99.4 %

Table 5.3 presents the overall nonpoint source loadings from direct nonpoint sources of loading into Muddy Creek. This includes cattle in the stream, failing septic systems, and uncontrolled discharges. The loadings from the direct discharges are several orders of magnitude higher than loadings from the land uses in Table 5.2. Since the direct discharges also occur at lower stream flows, very high levels of reduction are required to meet water quality targets. In the allocation scenario loadings from uncontrolled discharges and failing septic systems are completely eliminated. Loadings from cattle in the stream are reduced by 99 percent in order to meet the water quality standard.

Land use and animal populations vary slightly between subwatersheds in the Muddy Creek watershed. The load allocation that was developed for Muddy Creek takes into consideration the source loading differences between Muddy Creek subwatersheds. Appendix B presents the existing and allocated loads for each subwatershed within Muddy Creek. The impact of the load reductions on the instream fecal coliform bacteria concentration can be seen in the time-series plots presented in Appendix B for each of the eight subwatersheds.

5.4 Seasonality

Seasonal variation was explicitly included in the modeling approach for this TMDL. Fecal coliform accumulation rates for each land use were determined on a monthly basis. The monthly accumulation rates accounted for the temporal variation in activities within the watershed, including seasonal application of agricultural waste, grazing schedules of livestock, and seasonal variation in number of cows in the stream. Also, the use of continuous simulation modeling resulted in consideration of the seasonal aspects of rainfall patterns.

Seasonal variation was also accounted for in the allocation scenario. Reductions of fecal coliform loads were determined on a monthly basis by each land use in each subwatershed as discussed in Appendix B.

6.0 IMPLEMENTATION

6.1 Follow-up Monitoring

In 1991, DEQ installed an ambient water quality monitoring station on Muddy Creek about 0.4 mile upstream from the confluence with Dry River. In 1995, an ambient and biological station was added at a site 5.81 miles above the confluence. A second biological monitoring station was established 2.1 miles above the confluence in 1996. The two ambient stations are sampled monthly for fecal coliform bacteria and other conventional pollutants. The two biological monitoring stations are sampled twice a year for benthic organisms. These monitoring stations will be maintained by DEQ during the Muddy Creek TMDL development and restoration processes. DEQ and DCR will continue to use data from these monitoring stations for evaluating reductions in fecal bacteria counts and the effectiveness of the TMDL in attainment of water quality standards.

Monthly sampling for fecal coliform bacteria will continue at the two ambient stations until the violation rate of Virginia's fecal coliform standard, 1000 per 100 milliliters, is reduced to 10% or less. After this reduction in the fecal coliform violation rate is verified, in a subsequent biennial 303(d) water quality assessment the monitoring frequency for this parameter will be increased to two or more samples within a 30 day period. This sampling frequency is needed to provide the water quality data needed for evaluation and verification that the TMDL will attain and maintain Virginia's water quality standard, the geometric mean of 200 fecal coliform counts per 100 milliliters. Sampling at each of the two biological stations will continue at twice per year.

6.2 Reasonable Assurance of Implementation to Obtain Projected Load Reductions:

6.2.1 - Feasibility of Implementation to Meet Reduction Goals

Several load reduction scenarios were considered during development of this TMDL. Development of the final load reduction scenario was designed to result not only in a reduction in fecal loadings to Muddy Creek to a level that will be protective of human health and the Creek's use designation, but also to yield the most feasible implementation from a practical perspective. A number of key decisions were made in the development of the reduction scenario:

- Although the exclusion of livestock from streams appears to be the single most significant measure for reducing fecal loading, 100% removal of cattle from the streams is not feasible.
- Complete elimination of straight pipe discharges is consistent with health code requirements.
- Reductions of loading from barnyards and feedlots is the most feasible reduction for storm runoff, based on the ability to control drainage through these areas.
- The fecal load reduction associated with agricultural application of manure to crop and pasture lands was minimized.

6.2.2 - Future Implementation Activities

Virginia presently administers a number of water quality-related programs which will be utilized in making the recovery of Muddy Creek a reality:

A) Watershed Assessment and Planning:

- The Shenandoah-Potomac Tributary Strategy: This Tributary Strategy was completed as the combined effort of many state and local organizations, and identified nutrient load reduction goals associated with agricultural land uses for the northern/southern portion of the Shenandoah Valley region. Although this TMDL for Muddy Creek addresses fecal coliform loading, as opposed to nutrients, the sources of loading for each pollutant are similar and some management measures may be developed to address both. Additionally, Virginia intends to complete a TMDL for nitrate in the Muddy Creek watershed in the near future, and implementation for these two TMDL's will be accomplished in a coordinated fashion.
- Consistent with Virginia's multi-tiered approach to Watershed Restoration Action Strategy (WRAS) development, the Muddy Creek TMDL implementation plan will serve as a second tier or watershed level WRAS. The Muddy Creek WRAS will identify goals and processes for addressing water quality impairments in the creek and it will address the WRAS criteria or elements set forth in EPA guidance issued on June 9, 1998.
- Incorporation of the TMDL into DEQ's WQMP: As set out in Virginia's Continuous Planning Process (CPP), this TMDL will be incorporated into the Shenandoah/Potomac revised Water Quality management Plan (WQMP). Pursuant to Virginia Law, an implementation plan is required to be developed following adoption of the TMDL into that WQMP. Virginia DEQ and DCR will explore the coordination of the WQMP revision process and the WRAS development process to best satisfy this requirement of State law.
- Partnership w/Farm Bureau: Virginia has sought the assistance of agricultural community representatives, as well as other stakeholders in the Muddy Creek watershed, and will sponsor, with the Farm Bureau, a stakeholder's advisory committee which will be involved in the development of the implementation plan.

B) Watershed Funding: The Muddy Creek watershed has been identified as a priority for assessment and implementation by Virginia's Water Quality Assessment process (305/303), and by Virginia's Unified Watershed Assessment process. As implementation plans are developed, the following resources will be targeted to Muddy Creek:

- Virginia's Water Quality Improvement Fund
- DCR's NPS grant program (Section 319) and other Clean Water Act and SDWA funding programs
- Agricultural Cost Share
- etc....

6.3 TMDL Implementation Process

The goal of the Muddy Creek TMDL is to establish a path which will lead to expeditious attainment of water quality standards. The first step in this process was to develop an implementable TMDL for Muddy Creek. The second step is to develop a TMDL implementation plan, and the final step is to implement the TMDL.

Section 303(d) of the Clean Water Act and EPA's 303(d) regulation do not provide new implementing mechanisms for TMDL development. However, Virginia's 1997 Water Quality Monitoring, Information, and Restoration Act directs DEQ to develop a plan for the expeditious implementation of TMDLs.

DEQ plans to incorporate TMDL implementation plans as part of the 303(e) Water Quality Management Plans (WQMP). In response to the recent EPA/DEQ Memorandum of Understanding, DEQ submitted a Continuous Planning Process to EPA in which Virginia commits to updating the WQMPs, which will be the repository of TMDLs and the implementation plans. Each implementation plan will contain a reasonable assurance section which will detail the availability of funds for implementation of voluntary actions. One potential source of funding for implementation of the Muddy Creek TMDL is Virginia's Unified Watershed Assessment, an element of the Clean Water Action Plan. Virginia's Unified Watershed Assessment identified Muddy Creek as a high priority watershed which makes it eligible for new federal funding under Section 319 of the Clean Water Act. This funding is specifically targeted for implementation work associated with watershed restoration strategies.

Watershed stakeholders will have opportunities to provide input and participate in development of the implementation plan, with support from regional and local offices of VADEQ, VADCR and other participating assistance agencies. Current regulations of the Virginia Department of Health require correction of all straight pipes and failed septic systems, and it is recommended that all such sources be brought into compliance. Dairy parlor waste direct discharges and sinkhole dumps should be identified and corrected. Because it was difficult to obtain accurate numbers for these four sources during development of the TMDL, ground proofing may be needed as part of the implementation.

6.3.1 Phased Implementation Plan

Implementation of best management practices (BMPs) in the Muddy Creek watershed will occur in phases. The benefit of phased implementation is that as stream monitoring continues to occur, accurate measurements of progress being achieved are recorded. This approach provides a measure of quality control, given the uncertainties which exist in the developed TMDL model. The target for the first phase of implementation in the Muddy Creek watershed will be 10% violation of the 1,000 count/100mL instantaneous standard.

Using the model developed to represent existing conditions (see Sections 4.5 - 4.7), an allocation scenario was developed that would result in 10% violation of the 1,000 count/100mL instantaneous standard. For the Phase I allocation, the model was run for the representative hydrologic period 1991 through 1995.

The Phase I allocation that follows reflects the fact that reduction of direct sources of fecal coliform deposition into the stream is critical to reducing violations of the 1,000 count/100mL instantaneous standard. Reduction of sources that impact fecal loadings during storm events are less critical. The Phase 1 allocation requires no reduction in existing loads from land uses within the watershed as shown in Table 6.1. Inputs from failing septic systems and other uncontrolled direct discharges are completely eliminated in Phase 1 implementation, as shown in Table 6.2. Table 6.2 also shows that high levels of reduction are also needed from cattle in the stream to meet the reduction target for Phase I implementation.

Table 6.1. Overall Phase 1 fecal coliform bacteria nonpoint source allocations for the Muddy Creek watershed for the representative hydrologic period

Land use	Total annual loading for existing run (counts/year)	Total annual loading for allocation run (counts/year)	Percent reduction
Built-up	1.88E+10	1.88E+10	0 %
Farmstead	1.78E+10	1.78E+10	0 %
Forest	7.33E+10	7.33E+10	0 %
Barren	1.32E+08	1.32E+08	0 %
Cropland	2.48E+11	2.48E+11	0 %
Loafing lots	4.11E+12	4.11E+12	0 %
Pasture 1	1.72E+12	1.72E+12	0 %
Pasture 2	2.19E+11	2.19E+11	0 %
Pasture 3	3.34E+12	3.34E+12	0 %

Table 6.2. Phase 1 load allocations to direct nonpoint sources of cows in the stream, failing septic systems, and uncontrolled discharges (for the entire Muddy Creek watershed)

	Instream Cows (counts/year)			Failing septic systems (counts/year)			Uncontrolled discharges (counts/year)		
Subwater-shed	**Existing loads**	**Allocated loads**	**Percent Red.**	**Existing loads**	**Allocated loads**	**Percent Red.**	**Existing loads**	**Allocated loads**	**Percent Red.**
Muddy 3	5.37E+13	2.59E+12	95.2	6.14E+10	0	100	0	0	0
Muddy 2	2.44E+14	1.02E+13	95.8	2.51E+11	0	100	4.06E+13	0	100
War 3	1.46E+13	9.57E+11	93.5	1.42E+10	0	100	0	0	0
War 2	5.74E+13	5.80E+12	89.9	6.25E+10	0	100	4.06E+13	0	100
Buttermilk	5.17E+13	1.79E+12	96.5	5.11E+10	0	100	0	0	0
War 1	1.95E+13	3.54E+12	81.9	1.04E+11	0	100	0	0	0
Muddy 1	1.35E+14	5.65E+12	95.8	1.57E+11	0	100	0	0	0
Patterson	6.07E+12	1.84E+12	69.7	7.11E+10	0	100	0	0	0
TOTAL	5.8E+14	3.2E+13	94.4	7.7E+11	0	100	8.1E+13	0	100

6.4 Public Participation

The first public meeting held in Harrisonburg on September 16, 1998, to discuss the development of the draft Muddy Creek TMDL, was public noticed in the Harrisonburg Daily News-Record on August 31, 1998. Copies of presentation materials and diagrams outlining the development of the TMDL were available for public distribution. About 85 people attended the meeting. The public comment period ended on September 30.

A second public meeting on the development of the TMDL was requested by the Virginia Farm Bureau and was held in Mount Clinton on October 26, 1998. The Farm Bureau sent hundreds of letters of invitation and meet with community leaders to promote the meeting. More than 250 people, a large majority farmers from the watershed, attended this meeting.

A third public meeting to discuss the draft TMDL was held on December 15, 1998. This meeting was announced in the Virginia Register on December 7, 1998. The Farm Bureau also assisted in promoting the meeting. Approximately 140 people attended this meeting.

On January 4, 1999, a 30 day extension of the public comment period on the draft TMDL was announced in the Virginia Register. The comment period was extended until March 17, with the extension announced in the Virginia Register and Harrisonurg Daily News-Record on February 15, 1999. On April 27, 1999, a 30 day extension of the public comment on the draft TMDL was announced in the Virginia register. The Muddy Creek Citizens Watershed Advisory Group Reported that an additional public meeting was not needed.

A Muddy Creek Citizens Watershed Advisory Group was formed in early 1999. This group, which has reviewed and provided comments on the draft TMDL, will work with local DEQ and DCR staff to develop implementation strategies for the watershed.

REFERENCES

American Public Health Association (and others). 1985. *Standard Methods for the Examination of Water and Wastewater* 16th edition. Washington, D.C. As cited in Potomac Headwaters Agricultural Water Quality Report for Grant, Hampshire, Hardy, Mineral, and Pendleton Counties, Virginia. Prepared by Potomac Headwaters Interagency Water Quality Office, Moorefield, WV. May 1996.

Chapra, S. 1997. *Surface Water-Quality Modeling*. McGraw-Hill Publishers, Inc. New York.

Horsley & Witten, Inc. 1996. Identification and Evaluation of Nutrient and Bacterial Loadings to Maquoit Bay, Brunswick, and Freeport, Maine. Casco Bay Estuary Project.

Long Island Regional Planning Board (LIRPD). 1982. *The Long Island Segment of the National Urban Runoff Program*. Long Island Regional Planning Board.

Metcalf & Eddy. 1991. Wastewater Engineering: Treatment, Disposal, Reuse. 3rd edition. McGraw-Hill, Inc., New York.

Moore, J.A., M.E. Grismer, S.R. Crane, and J.R. Miner. 1982. *Evaluating Dairy Waste Management Systems' Influence on Fecal Coliform Concentration in Runoff.* Agricultural Experiment Station Bulletin No. 658, Oregon State University, Corvallis, Oregon.

Novotny, V., K.R. Imhoff, M. Othoff, and P.A. Krenkel. 1989. *Karl Imhoff's Handbook of Urban Drainage and Wastewater Disposal*. Wiley Interscience, New York.

Novotny, V., and H. Olem. 1994. *Water Quality: Prevention, Identification, and Management of Diffuse Pollution*. Van Nostrand Reinhold, New York.

NSFC. 1993. *National Onsite Wastewater Treatment: Summary of Onsite Systems in the United States, 1993.* National Small Flows Clearinghouse, Morgantown, WV.

NRCS. 1998. U.S. Department of Agriculture, Natural Resources Conservation Service, memo dated June 2, 1998.

Palace, M. 1996. *Development of an Animal Waste Nutrient Mass Balance to Determine Pasture Loading and Compare Cropland Inputs.* Chesapeake Bay Program Office.

USEPA. 1988. *Storm Water Management Model User's Manual, Version IV.* U.S. Environmental Protection Agency, Athens, GA. EPA 600/3-88-001a.

USEPA. 1991a. *Guidance for Water Quality-based Decisions: The TMDL Process*. U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA 440/4-91-001. April 1991.

USEPA. 1998. *Better Assessment Science Integrating Point and Nonpoint Sources, BASINS, Version 2.0 User's Manual.* U.S. Environmental Protection Agency, Office of Water, Washington, DC.

VADEQ. 1998. *Virginia Draft 1998 303(d) List.*

VADEQ. 1997. TMDL Study on Six Watersheds in the Shenandoah River Basin. March 1997.

APPENDIX A

Table A.1. Land use distribution within the Muddy Creek watershed, including Virginia classifications.

Land use category	VA categories included	Subwatershed acreages								Total acres
		22	23	24	25	26	27	28	29	
Cropland	Row crop (2110)	669.79	1917.71	108.72	682.08	235.36	61.91	779.84	31.05	4486.46
	Gullied row crop (2111)		103.13					9.23		112.36
	Row crop stripped (2113)	46.38	145.67	10.12	79.95			10.89		293.01
	Rotational hay (2114)		65.04	3.94	5.74	45.51	8.13	113.83		242.19
	Orchard (221)		17.52							17.52
	Total	716.17	2249.07	122.78	767.77	280.87	70.04	913.79	31.05	5151.54
Pasture 1	Improved pasture/hayfield (2122)	457.04	1954.36	142.27	442.81	407.82	98.96	1141.89	38.2	4683.35
	Total	457.04	1954.36	142.27	442.81	407.82	98.96	1141.89	38.2	4683.35
Pasture 2	Unimproved pasture (2123)		0.55	8.83	6.16	3.46		2.81		21.81
	Grazed woodland (43)	14.93	122.76		26.56	24.93	10.27	45.68	23.39	268.52
	Total	14.93	123.31	8.83	32.72	28.39	10.27	48.49	23.39	290.33
Pasture 3	Overgrazed pasture (2124)	60.71	446.91		112.71	96.5	95.1	219.77	1.97	1033.67
	Total	60.71	446.91	0	112.71	96.5	95.1	219.77	1.97	1033.67
Farmstead	Housed poultry (2321)	17.61	22.94	3.47	23.27	2.45	8.99	14.55		93.28
	Farmstead (13)	86.08	292.25	19.74	88.02	20.01	3.51	136.11	4.08	649.8
	Farmsteads w/ dairy waste facilities (813)	48.09	29	6.53	16.92	19.68		10.76		130.98
	Large individual dairy waste facilities (8)	0.22		0.12		0.14				0.48
	Total	152	344.19	29.86	128.21	42.28	12.5	161.42	4.08	874.54
Built-up	Built up <50% porous (11)		12	39.86						51.86
	Built up >50% porous (12)		62.96	6.64		0.04				69.64
	Wooded residential (44)	8.55	54.33		12.77	11.55	8.04	192.6		287.84
	Rural Residential (14)	26.55	204.16	15.06	16.76	84.97	75.58	57.59	1.01	481.68
	Unclassified (999)		21.03		3.24	3.32	13.71	19.02	6.35	66.67
	Total	35.1	354.48	61.56	32.77	99.88	97.33	269.21	7.36	957.69
Loafing lots	Dairy loafing lots (2312)	50.59	45.09	3.56	22.09	15.8		11.12		148.25
	Unhoused poultry (2322)		8.35					2.45		10.8
	Total	50.59	53.44	3.56	22.09	15.8	0	13.57	0	159.05
Forest	Forest land (40)	105.55	992.5		81.39	350.19	2300.99	1303.16	1730.13	6863.91
	Total	105.55	992.5	0	81.39	350.19	2300.99	1303.16	1730.13	6863.91
Barren	Recently harvested woodland-clear cut (41)					1.62			1	2.62
	Recently harvested woodland-not clear cut(42)									0
	Transitional or disturbed sites (7)					0.77			6.73	7.5
	Total	0	0	0	0	2.39	0	0	7.73	10.12
TOTAL		1592.09	6518.26	368.86	1620.47	1324.12	2685.19	4071.3	1843.91	20024.2

KEY TO SUBWATERSHEDS IN TABLE A.1.

Subwatershed Number in Table A.1.	Name of Subwatershed in Figure 3.2.
22	Muddy 3
23	Muddy 2
24	War 3
25	War 2
26	Buttermilk
27	War 1
28	Muddy 1
29	Patterson

APPENDIX B

B.1 Seasonal Variations

Seasonal variation was explicitly included in the modeling approach for this TMDL. Fecal coliform accumulation rates for each land use were determined on a monthly basis. The monthly accumulation rates accounted for the temporal variation in activities within the watershed, including seasonal application of agricultural waste, grazing schedules of livestock, and seasonal variation in number of cows in the stream. Also, the use of continuous simulation modeling resulted in consideration of the seasonal aspects of rainfall patterns.

Seasonal variation was also accounted for in the allocation scenario. Reductions of fecal coliform loads were determined on a monthly basis for each source as shown in the following tables:Table B.1 presents load allocations for Builtup, Farmstead, Forest and Barren lands; Table B.2 presents load allocations for Cropland and Loafing Lots; Table B.3 presents load allocations for Pasture 1, Pasture 2, and Pasture 3; and Table B.4 shows monthly existing and allocated loadings for instream deposition by cattle.

Table B.1. Monthly fecal coliform bacteria nonpoint source load allocations for Builtup, Farmstead, Forest and Barren lands in the Muddy Creek watershed

Mon	Builtup loads (counts/month)		Farmstead loads (counts/month)		Forest loads (counts/month)		Barren loads (counts/month)	
	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction
Jan	2.01E+09	0	1.90E+09	0	8.24E+09	0	1.57E+07	0
Feb	1.45E+09	0	1.36E+09	0	6.98E+09	0	1.20E+07	0
Mar	2.91E+09	0	2.73E+09	0	1.44E+10	0	2.40E+07	0
Apr	1.87E+09	0	1.74E+09	0	1.03E+10	0	1.65E+07	0
May	1.48E+09	0	1.41E+09	0	6.31E+09	0	1.01E+07	0
Jun	1.26E+09	0	1.22E+09	0	3.63E+09	0	6.39E+06	0
Jul	1.60E+09	0	1.55E+09	0	4.44E+09	0	8.44E+06	0
Aug	1.21E+09	0	1.16E+09	0	4.19E+09	0	8.20E+06	0
Sep	1.12E+09	0	1.10E+09	0	1.98E+09	0	4.11E+06	0
Oct	1.05E+09	0	9.88E+08	0	4.35E+09	0	8.28E+06	0
Nov	1.34E+09	0	1.29E+09	0	3.63E+09	0	8.18E+06	0
Dec	1.48E+09	0	1.40E+09	0	4.95E+09	0	1.05E+07	0
TOT	1.88E+10	0	1.78E+10	0	7.33E+10	0	1.32E+08	0

Table B.2. Monthly fecal coliform bacteria nonpoint source load allocations for Cropland and Loafing Lots lands in the Muddy Creek watershed

Mon	Cropland loads (counts/month)			Loafing lots loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	6.96E+09	6.70E+09	3.73	3.02E+11	6.14E+10	79.69
Feb	1.38E+10	1.22E+10	10.97	2.73E+11	5.07E+10	81.44
Mar	1.08E+11	9.34E+10	13.58	1.00E+12	1.92E+11	80.78
Apr	7.36E+10	6.13E+10	16.79	7.18E+11	1.40E+11	80.53
May	7.79E+09	7.34E+09	5.74	1.94E+11	3.59E+10	81.49
Jun	3.09E+09	2.99E+09	3.08	1.14E+11	1.92E+10	83.16
Jul	3.80E+09	3.65E+09	3.97	3.18E+11	5.86E+10	81.60
Aug	1.01E+10	8.85E+09	12.45	3.38E+11	6.48E+10	80.85
Sep	2.00E+09	1.95E+09	2.31	4.12E+09	7.05E+08	82.87
Oct	1.15E+10	1.03E+10	10.58	4.11E+11	9.98E+10	75.70
Nov	3.14E+09	2.87E+09	8.53	2.93E+11	5.38E+10	81.63
Dec	4.28E+09	4.15E+09	3.20	1.42E+11	3.15E+10	77.77
TOT	2.48E+11	2.16E+11	13.07	4.11E+12	8.08E+11	80.32

Table B.3. Monthly fecal coliform bacteria nonpoint source load allocations for Pasture 1, Pasture 2, and Pasture 3 lands in the Muddy Creek watershed

	Pasture 1 loads (counts/month)			Pasture 2 loads (counts/month)			Pasture 3 loads (counts/month)		
Mon	Existing	Allocated	Percent Red.	Existing	Allocated	Percent Red.	Existing	Allocated	Percent Red.
Jan	7.59E+10	4.46E+10	41.25	1.77E+10	9.99E+09	43.59	3.29E+11	1.88E+11	43.07
Feb	1.08E+11	6.25E+10	41.94	1.55E+10	8.88E+09	42.71	2.47E+11	1.41E+11	43.03
Mar	4.95E+11	2.89E+11	41.58	5.42E+10	3.21E+10	40.70	7.85E+11	4.60E+11	41.48
Apr	3.37E+11	1.92E+11	43.03	3.64E+10	2.09E+10	42.53	5.22E+11	2.98E+11	42.83
May	8.10E+10	4.75E+10	41.38	9.45E+09	5.47E+09	42.09	1.35E+11	7.65E+10	43.25
Jun	4.40E+10	2.45E+10	44.30	5.41E+09	2.85E+09	47.32	7.65E+10	4.01E+10	47.58
Jul	1.22E+11	7.00E+10	42.82	1.52E+10	8.40E+09	44.76	2.20E+11	1.22E+11	44.64
Aug	1.37E+11	7.94E+10	41.95	1.65E+10	9.31E+09	43.56	2.39E+11	1.35E+11	43.43
Sep	3.22E+09	2.43E+09	24.58	2.80E+08	1.93E+08	30.92	2.99E+09	1.73E+09	42.08
Oct	2.05E+11	1.33E+11	34.96	2.48E+10	1.62E+10	34.67	3.61E+11	2.35E+11	34.97
Nov	6.63E+10	3.79E+10	42.82	1.33E+10	7.35E+09	44.66	2.33E+11	1.32E+11	43.55
Dec	4.41E+10	2.62E+10	40.71	1.02E+10	5.79E+09	43.19	1.89E+11	1.08E+11	42.78
TOT	1.72E+12	1.01E+12	41.25	2.19E+11	1.28E+11	41.76	3.34E+12	1.94E+12	42.04

Table B.4. Allocations for fecal coliform loads from cows in the stream for the Muddy Creek watershed.

Month	Existing load (counts/month)	Allocated load (counts/month)	Percent reduction
January	1.8E+11	1.8E+11	0%
February	1.6E+11	1.6E+11	0%
March	2.9E+13	1.3E+12	95.4%
April	6.1E+13	4.8E+11	99.2%
May	6.3E+13	6.9E+11	98.9%
June	9.1E+13	3.4E+11	99.6%
July	9.4E+13	1.4E+11	99.9%
August	9.4E+13	6.1E+10	99.9%
September	6.1E+13	1.4E+11	99.8%
October	6.3E+13	1.7E+11	99.7%
November	2.8E+13	3.0E+11	98.9%
December	1.8E+11	1.8E+11	0%
TOTAL	5.8E+14	4.1E+12	99.3%

B.2 Subwatershed Allocations

Land use and animal populations vary slightly between subwatersheds in the Muddy Creek watershed. The load allocation that was developed for Muddy Creek takes into consideration the source loading differences between Muddy Creek subwatersheds. Sections B.2.1 through B.2.8 present the existing and allocated loads for the subwatersheds within Muddy Creek.

B.2.1 Muddy 3

Table B.5 presents the load allocations to Built-up, Farmstead, and Forest lands in the Muddy 3 subwatershed. Table B.6 contains the load allocations to Cropland and Loafing Lots and Table B.7 contains the load allocations to the pasturelands (Pasture 1, Pasture 2, and Pasture 3) in the Muddy 3 subwatershed.

Table B.8 presents the load allocations for loads from cows directly discharging fecal coliform into the streams for subwatershed Muddy 3. The table presents the existing fecal coliform load from cows in the stream, the allocated load, and the percent reduction.

Table B.5. Load allocations for Built-up, Farmstead, and Forest lands in the Muddy 3 subwatershed

Mon	Builtup loads (counts/month)		Farmstead loads (counts/month)		Forest loads (counts/month)	
	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction
Jan	7.39E+07	0	3.30E+08	0	1.27E+08	0
Feb	5.33E+07	0	2.37E+08	0	1.07E+08	0
Mar	1.07E+08	0	4.75E+08	0	2.21E+08	0
Apr	6.74E+07	0	2.98E+08	0	1.57E+08	0
May	5.43E+07	0	2.45E+08	0	9.71E+07	0
Jun	4.66E+07	0	2.14E+08	0	5.55E+07	0
Jul	5.87E+07	0	2.69E+08	0	6.83E+07	0
Aug	4.45E+07	0	2.01E+08	0	6.44E+07	0
Sep	4.00E+07	0	1.86E+08	0	3.05E+07	0
Oct	3.85E+07	0	1.72E+08	0	6.70E+07	0
Nov	4.80E+07	0	2.18E+08	0	5.52E+07	0
Dec	5.42E+07	0	2.44E+08	0	7.62E+07	0
TOT	6.86E+08 counts/year	0	3.09E+09 counts/year	0	1.13E+09 counts/year	0

Table B.6. Load allocations for Cropland and Loafing Lots in the Muddy 3 subwatershed

Mon	Cropland loads (counts/month)			Loafing lots loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	9.68E+08	9.31E+08	3.77	9.62E+10	1.96E+10	79.67
Feb	1.91E+09	1.70E+09	11.03	8.69E+10	1.61E+10	81.42
Mar	1.50E+10	1.30E+10	13.56	3.18E+11	6.11E+10	80.78
Apr	9.77E+09	8.52E+09	12.80	2.15E+11	4.44E+10	79.40
May	1.08E+09	1.02E+09	5.71	6.18E+10	1.14E+10	81.50
Jun	4.23E+08	4.16E+08	1.70	3.46E+10	6.12E+09	82.30
Jul	5.28E+08	5.07E+08	3.98	1.01E+11	1.86E+10	81.59
Aug	1.40E+09	1.23E+09	12.39	1.08E+11	2.06E+10	80.84
Sep	2.78E+08	2.71E+08	2.31	1.24E+09	2.24E+08	81.87
Oct	1.60E+09	1.43E+09	10.67	1.31E+11	3.17E+10	75.71
Nov	4.19E+08	3.99E+08	4.84	8.74E+10	1.71E+10	80.42
Dec	5.96E+08	5.76E+08	3.21	4.51E+10	1.00E+10	77.79
TOT	3.40E+10	3.00E+10	11.81	1.29E+12	2.57E+11	80.01

Table B.7. Load allocations for Pasture 1, Pasture 2, and Pasture 3 in the Muddy 3 subwatershed

	Pasture 1 loads (counts/month)			Pasture 2 loads (counts/month)			Pasture 3 loads (counts/month)		
Mon	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	7.41E+09	4.35E+09	41.23	8.79E+08	4.96E+08	43.58	1.94E+10	1.10E+10	43.04
Feb	1.05E+10	6.10E+09	41.97	7.70E+08	4.41E+08	42.76	1.45E+10	8.28E+09	43.03
Mar	4.83E+10	2.82E+10	41.55	2.69E+09	1.60E+09	40.68	4.61E+10	2.70E+10	41.50
Apr	3.13E+10	1.87E+10	40.25	1.71E+09	1.04E+09	39.28	2.92E+10	1.75E+10	40.09
May	7.90E+09	4.63E+09	41.32	4.70E+08	2.72E+08	42.16	7.92E+09	4.50E+09	43.19
Jun	4.14E+09	2.39E+09	42.19	2.56E+08	1.41E+08	44.87	4.32E+09	2.36E+09	45.47
Jul	1.20E+10	6.83E+09	42.88	7.57E+08	4.17E+08	44.91	1.29E+10	7.14E+09	44.69
Aug	1.34E+10	7.74E+09	42.14	8.20E+08	4.62E+08	43.63	1.40E+10	7.92E+09	43.59
Sep	3.08E+08	2.37E+08	22.94	1.35E+07	9.60E+06	28.65	1.69E+08	1.02E+08	39.72
Oct	2.00E+10	1.30E+10	34.81	1.24E+09	8.06E+08	34.74	2.11E+10	1.38E+10	34.77
Nov	6.16E+09	3.70E+09	39.94	6.21E+08	3.64E+08	41.44	1.30E+10	7.73E+09	40.63
Dec	4.30E+09	2.55E+09	40.69	5.07E+08	2.87E+08	43.29	1.11E+10	6.35E+09	42.83
TOT	1.66E+11	9.85E+10	40.54	1.07E+10	6.33E+09	41.00	1.94E+11	1.14E+11	41.36

Table B.8. Allocations for fecal coliform loads from cows in the stream for the Muddy 3 subwatershed

Month	Existing load (counts/month)	Allocated load (counts/month)	Percent reduction
January	1.55E+10	1.55E+10	0.0
February	1.40E+10	1.40E+10	0.0
March	2.64E+12	1.32E+11	95.0
April	5.59E+12	5.59E+10	99.0
May	5.78E+12	5.78E+10	99.0
June	8.38E+12	8.38E+10	99.0
July	8.66E+12	0.00E+00	100.0
August	8.66E+12	0.00E+00	100.0
September	5.59E+12	0.00E+00	100.0
October	5.78E+12	5.78E+10	99.0
November	2.55E+12	2.55E+10	99.0
December	1.55E+10	1.55E+10	0.0
TOTAL	5.37E+13	4.58E+11	99.1

B.2.2 Muddy 2

Table B.9 presents the load allocations to Built-up, Farmstead, and Forest lands in the Muddy 2 subwatershed. Table B.10 contains the load allocations to Cropland and Loafing Lots, and Table B.11 contains the load allocations to the pasturelands (Pasture 1, Pasture 2, and Pasture 3) in the Muddy 2 subwatershed.

Table B.12 presents the load allocations for loads from cows directly discharging fecal coliform into the streams for subwatershed Muddy 2. The table presents the existing fecal coliform load from cows in the stream, the allocated load, and the percent reduction.

Table B.9. Load allocations for Built-up, Farmstead and Forest lands in the Muddy 2 subwatershed

	Builtup loads (counts/month)		Farmstead loads (counts/month)		Forest loads (counts/month)	
Mon	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction
Jan	7.46E+08	0	7.47E+08	0	1.19E+09	0
Feb	5.37E+08	0	5.35E+08	0	1.01E+09	0
Mar	1.08E+09	0	1.08E+09	0	2.08E+09	0
Apr	6.80E+08	0	6.74E+08	0	1.48E+09	0
May	5.47E+08	0	5.54E+08	0	9.12E+08	0
Jun	4.70E+08	0	4.86E+08	0	5.22E+08	0
Jul	5.91E+08	0	6.09E+08	0	6.42E+08	0
Aug	4.49E+08	0	4.55E+08	0	6.06E+08	0
Sep	4.02E+08	0	4.21E+08	0	2.86E+08	0
Oct	3.89E+08	0	3.89E+08	0	6.29E+08	0
Nov	4.83E+08	0	4.94E+08	0	5.19E+08	0
Dec	5.47E+08	0	5.51E+08	0	7.16E+08	0
TOT	6.92E+09	0	6.99E+09	0	1.06E+10	0

Table B.10. Load allocations for Cropland and Loafing Lots in the Muddy 2 subwatershed

Mon	Cropland loads (counts/month)			Loafing lots loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	3.04E+09	2.93E+09	3.71	1.02E+11	2.06E+10	79.69
Feb	6.00E+09	5.35E+09	10.94	9.18E+10	1.70E+10	81.44
Mar	4.72E+10	4.08E+10	13.56	3.36E+11	6.45E+10	80.78
Apr	3.07E+10	2.67E+10	12.78	2.27E+11	4.70E+10	79.33
May	3.40E+09	3.20E+09	5.73	6.52E+10	1.21E+10	81.50
Jun	1.33E+09	1.31E+09	1.72	3.65E+10	6.46E+09	82.29
Jul	1.66E+09	1.59E+09	3.99	1.07E+11	1.97E+10	81.61
Aug	4.41E+09	3.86E+09	12.53	1.14E+11	2.18E+10	80.85
Sep	8.72E+08	8.52E+08	2.29	1.31E+09	2.37E+08	81.85
Oct	5.02E+09	4.50E+09	10.51	1.38E+11	3.36E+10	75.65
Nov	1.32E+09	1.25E+09	4.76	9.24E+10	1.81E+10	80.45
Dec	1.87E+09	1.81E+09	3.19	4.76E+10	1.06E+10	77.75
TOT	1.07E+11	9.42E+10	11.79	1.36E+12	2.72E+11	80.00

Table B.11. Load allocations for Pasture 1, Pasture 2 and Pasture 3 in the Muddy 2 subwatershed

Mon	Pasture 1 loads (counts/month)			Pasture 2 loads (counts/month)			Pasture 3 loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	3.17E+10	1.86E+10	41.24	7.54E+09	4.25E+09	43.64	1.42E+11	8.11E+10	43.07
Feb	4.49E+10	2.61E+10	41.96	6.60E+09	3.78E+09	42.71	1.07E+11	6.10E+10	43.00
Mar	2.07E+11	1.21E+11	41.61	2.31E+10	1.37E+10	40.74	3.40E+11	1.99E+11	41.52
Apr	1.34E+11	8.01E+10	40.27	1.47E+10	8.89E+09	39.38	2.15E+11	1.29E+11	40.13
May	3.38E+10	1.98E+10	41.32	4.02E+09	2.33E+09	42.13	5.83E+10	3.31E+10	43.21
Jun	1.77E+10	1.02E+10	42.07	2.20E+09	1.21E+09	44.84	3.18E+10	1.73E+10	45.47
Jul	5.10E+10	2.92E+10	42.77	6.47E+09	3.57E+09	44.72	9.50E+10	5.26E+10	44.57
Aug	5.70E+10	3.31E+10	41.87	7.02E+09	3.96E+09	43.60	1.03E+11	5.84E+10	43.42
Sep	1.32E+09	1.01E+09	23.00	1.15E+08	8.22E+07	28.67	1.24E+09	7.49E+08	39.76
Oct	8.56E+10	5.57E+10	34.98	1.06E+10	6.91E+09	34.71	1.56E+11	1.01E+11	35.02
Nov	2.63E+10	1.58E+10	39.80	5.33E+09	3.13E+09	41.37	9.59E+10	5.69E+10	40.71
Dec	1.84E+10	1.09E+10	40.73	4.33E+09	2.46E+09	43.20	8.16E+10	4.67E+10	42.77
TOT	7.08E+11	4.21E+11	40.54	9.19E+10	5.42E+10	41.00	1.43E+12	8.37E+11	41.38

Table B.12. Allocations for fecal coliform loads from cows in the stream for the Muddy 2 subwatershed

Month	Existing load (counts/month)	Allocated load (counts/month)	Percent reduction
January	7.38E+10	7.38E+10	0.0
February	6.67E+10	6.67E+10	0.0
March	1.20E+13	4.81E+11	96.0
April	2.54E+13	2.54E+11	99.0
May	2.63E+13	2.63E+11	99.0
June	3.81E+13	0.00E+00	100.0
July	3.94E+13	0.00E+00	100.0
August	3.94E+13	0.00E+00	100.0
September	2.54E+13	0.00E+00	100.0
October	2.63E+13	0.00E+00	100.0
November	1.16E+13	1.16E+11	99.0
December	7.38E+10	7.38E+10	0.0
TOTAL	2.44E+14	1.33E+12	99.5

B.2.3 War 3

Table B.13 presents the load allocations to Built-up, Farmstead and Forest lands in the War 3 subwatershed. Table B.14 contains the load allocations to Cropland and Loafing Lots, and Table B.15 contains the load allocations to the pasturelands (Pasture 1, Pasture 2, and Pasture 3) in the War 3 subwatershed.

Table B.16 presents the load allocations for loads from cows directly discharging fecal coliform into the streams for subwatershed War 3. The table presents the existing fecal coliform load from cows in the stream, the allocated load, and the percent reduction.

Table B.13. Load allocations for Built-up and Farmstead lands in the War 3 subwatershed

	Builtup loads (counts/month)		Farmstead loads (counts/month)	
Mon	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction
Jan	1.30E+08	0	6.50E+07	0
Feb	9.33E+07	0	4.65E+07	0
Mar	1.87E+08	0	9.35E+07	0
Apr	1.28E+08	0	6.32E+07	0
May	9.50E+07	0	4.82E+07	0
Jun	7.94E+07	0	4.08E+07	0
Jul	1.03E+08	0	5.30E+07	0
Aug	7.80E+07	0	3.96E+07	0
Sep	7.95E+07	0	4.18E+07	0
Oct	6.76E+07	0	3.38E+07	0
Nov	9.44E+07	0	4.81E+07	0
Dec	9.49E+07	0	4.80E+07	0
TOT	1.23E+09	0	6.21E+08	0

Table B.14. Load allocations for Cropland and Loafing Lots in the War 3 subwatershed

Mon	Cropland loads (counts/month)			Loafing lots loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	1.66E+08	1.60E+08	3.74	6.77E+09	1.37E+09	79.69
Feb	3.27E+08	2.92E+08	10.84	6.13E+09	1.14E+09	81.48
Mar	2.58E+09	2.23E+09	13.59	2.24E+10	4.30E+09	80.78
Apr	2.03E+09	1.46E+09	28.19	1.87E+10	3.13E+09	83.23
May	1.86E+08	1.75E+08	5.66	4.35E+09	8.04E+08	81.49
Jun	7.71E+07	7.14E+07	7.41	2.91E+09	4.31E+08	85.21
Jul	9.05E+07	8.69E+07	3.98	7.12E+09	1.31E+09	81.59
Aug	2.41E+08	2.11E+08	12.41	7.58E+09	1.45E+09	80.86
Sep	4.76E+07	4.65E+07	2.35	1.07E+08	1.58E+07	85.21
Oct	2.74E+08	2.46E+08	10.54	9.18E+09	2.23E+09	75.70
Nov	8.47E+07	6.84E+07	19.22	7.69E+09	1.20E+09	84.34
Dec	1.02E+08	9.88E+07	3.22	3.17E+09	7.04E+08	77.81
TOT	6.20E+09	5.14E+09	17.14	9.61E+10	1.81E+10	81.16

Table B.15. Load allocations for Pasture 1 and Pasture 2 in the War 3 subwatershed

Mon	Pasture 1 loads (counts/month)			Pasture 2 loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	2.31E+09	1.36E+09	41.29	5.39E+08	3.04E+08	43.58
Feb	3.27E+09	1.90E+09	41.97	4.72E+08	2.70E+08	42.70
Mar	1.50E+10	8.80E+09	41.52	1.65E+09	9.80E+08	40.69
Apr	1.20E+10	5.84E+09	51.37	1.29E+09	6.38E+08	50.69
May	2.46E+09	1.44E+09	41.36	2.88E+08	1.67E+08	42.13
Jun	1.53E+09	7.45E+08	51.34	1.88E+08	8.67E+07	53.89
Jul	3.72E+09	2.13E+09	42.79	4.63E+08	2.56E+08	44.75
Aug	4.15E+09	2.41E+09	41.89	5.02E+08	2.84E+08	43.40
Sep	1.05E+08	7.39E+07	29.91	9.37E+06	5.89E+06	37.19
Oct	6.22E+09	4.06E+09	34.85	7.58E+08	4.95E+08	34.59
Nov	2.39E+09	1.15E+09	51.71	4.77E+08	2.24E+08	53.08
Dec	1.34E+09	7.96E+08	40.64	3.10E+08	1.76E+08	43.21
TOT	5.46E+10	3.07E+10	43.73	6.95E+09	3.89E+09	44.09

Table B.16. Allocations for fecal coliform loads from cows in the stream for the War 3 subwatershed

Month	Existing load (counts/month)	Allocated load (counts/month)	Percent reduction
January	4.57E+09	4.57E+09	0.0
February	4.13E+09	4.13E+09	0.0
March	7.20E+11	2.16E+10	97.0
April	1.52E+12	0.00E+00	100.0
May	1.57E+12	0.00E+00	100.0
June	2.28E+12	2.28E+10	99.0
July	2.36E+12	2.36E+10	99.0
August	2.36E+12	0.00E+00	100.0
September	1.52E+12	1.52E+10	99.0
October	1.57E+12	1.57E+10	99.0
November	6.97E+11	6.97E+09	99.0
December	4.57E+09	4.57E+09	0.0
TOTAL	1.46E+13	1.19E+11	99.2

B.2.4 War 2

Table B.17 presents the load allocations to Built-up, Farmstead and Forest lands in the War 2 subwatershed. Table B.18 contains the load allocations to Cropland and Loafing Lots, and Table B.19 contains the load allocations to the pasturelands (Pasture 1, Pasture 2, and Pasture 3) in the War 2 subwatershed.

Table B.20 presents the load allocations for loads from cows directly discharging fecal coliform into the streams for subwatershed War 2. The table presents the existing fecal coliform load from cows in the stream, the allocated load, and the percent reduction.

Table B.17. Load allocations for Built-up, Farmstead, and Forest lands in the War 2 subwatershed

	Builtup loads (counts/month)		Farmstead loads (counts/month)		Forest loads (counts/month)	
Mon	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction
Jan	6.90E+07	0	2.78E+08	0	9.77E+07	0
Feb	4.97E+07	0	1.99E+08	0	8.28E+07	0
Mar	9.98E+07	0	4.01E+08	0	1.70E+08	0
Apr	6.79E+07	0	2.71E+08	0	1.31E+08	0
May	5.06E+07	0	2.06E+08	0	7.48E+07	0
Jun	4.23E+07	0	1.75E+08	0	4.55E+07	0
Jul	5.47E+07	0	2.27E+08	0	5.26E+07	0
Aug	4.15E+07	0	1.69E+08	0	4.97E+07	0
Sep	4.23E+07	0	1.79E+08	0	2.26E+07	0
Oct	3.59E+07	0	1.45E+08	0	5.16E+07	0
Nov	5.02E+07	0	2.06E+08	0	5.04E+07	0
Dec	5.06E+07	0	2.05E+08	0	5.87E+07	0
TOT	6.55E+08	0	2.66E+09	0	8.88E+08	0

Table B.18. Load allocations for Cropland and Loafing Lots in the War 2 subwatershed

Mon	Cropland loads (counts/month)			Loafing lots loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	1.04E+09	9.99E+08	3.76	4.20E+10	8.52E+09	79.69
Feb	2.05E+09	1.82E+09	11.05	3.80E+10	7.04E+09	81.47
Mar	1.61E+10	1.39E+10	13.63	1.39E+11	2.67E+10	80.78
Apr	1.27E+10	9.14E+09	28.07	1.16E+11	1.94E+10	83.21
May	1.16E+09	1.09E+09	5.73	2.69E+10	4.98E+09	81.48
Jun	4.82E+08	4.46E+08	7.45	1.80E+10	2.67E+09	85.22
Jul	5.66E+08	5.44E+08	3.92	4.42E+10	8.13E+09	81.60
Aug	1.51E+09	1.32E+09	12.38	4.70E+10	9.01E+09	80.84
Sep	2.98E+08	2.91E+08	2.34	6.63E+08	97974800	85.22
Oct	1.72E+09	1.53E+09	10.70	5.70E+10	1.38E+10	75.71
Nov	5.30E+08	4.28E+08	19.29	4.76E+10	7.46E+09	84.31
Dec	6.38E+08	6.18E+08	3.23	1.97E+10	4.37E+09	77.78
TOT	3.88E+10	3.21E+10	17.14	5.96E+11	1.12E+11	81.15

Table B.19. Load allocations for Pasture 1, Pasture 2, and Pasture 3 in the War 2 subwatershed

Mon	Pasture 1 loads (counts/month)			Pasture 2 loads (counts/month)			Pasture 3 loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	7.18E+09	4.22E+09	41.23	2.00E+09	1.13E+09	43.51	3.59E+10	2.04E+10	43.06
Feb	1.02E+10	5.91E+09	41.84	1.75E+09	1E+09	42.65	2.70E+10	1.54E+10	43.00
Mar	4.68E+10	2.74E+10	41.56	6.11E+09	3.63E+09	40.61	8.57E+10	5.01E+10	41.54
Apr	3.74E+10	1.82E+10	51.43	4.79E+09	2.36E+09	50.71	6.70E+10	3.25E+10	51.50
May	7.67E+09	4.48E+09	41.56	1.07E+09	6.18E+08	41.99	1.47E+10	8.34E+09	43.22
Jun	4.77E+09	2.32E+09	51.35	6.96E+08	3.22E+08	53.81	9.62E+09	4.38E+09	54.48
Jul	1.16E+10	6.61E+09	42.80	1.72E+09	9.49E+08	44.79	2.40E+10	1.33E+10	44.70
Aug	1.29E+10	7.51E+09	41.98	1.86E+09	1.05E+09	43.49	2.61E+10	1.47E+10	43.45
Sep	3.28E+08	2.3E+08	29.93	3.47E+07	21827200	37.16	3.76E+08	1.89E+08	49.74
Oct	1.94E+10	1.26E+10	34.86	2.80E+09	1.83E+09	34.50	3.94E+10	2.56E+10	35.09
Nov	7.43E+09	3.58E+09	51.81	1.76E+09	8.29E+08	52.99	3.03E+10	1.44E+10	52.60
Dec	4.17E+09	2.47E+09	40.70	1.15E+09	6.54E+08	43.06	2.06E+10	1.18E+10	42.84
TOT	1.70E+11	9.55E+10	43.77	2.57E+10	1.44E+10	44.04	3.81E+11	2.11E+11	44.55

Table B.20. Allocations for fecal coliform loads from cows in the stream for the War 2 subwatershed

Month	Existing load (counts/month)	Allocated load (counts/month)	Percent reduction
January	1.72E+10	1.72E+10	0.0
February	1.56E+10	1.56E+10	0.0
March	2.82E+12	1.13E+11	96.0
April	5.98E+12	5.98E+10	99.0
May	6.17E+12	0.00E+00	100.0
June	8.96E+12	8.96E+10	99.0
July	9.26E+12	0.00E+00	100.0
August	9.26E+12	0.00E+00	100.0
September	5.98E+12	5.98E+10	99.0
October	6.17E+12	0.00E+00	100.0
November	2.73E+12	0.00E+00	100.0
December	1.72E+10	1.72E+10	0.0
TOTAL	5.74E+13	3.72E+11	99.4

B.2.5 Buttermilk

Table B.21 presents the load allocations to Built-up, Farmstead and Forest lands in the Buttermilk subwatershed. Table B.22 contains the load allocations to Cropland and Loafing Lots, and Table B.23 contains the load allocations to the pasturelands (Pasture 1, Pasture 2, and Pasture 3) in the Buttermilk subwatershed.

Table B.24 presents the load allocations for loads from cows directly discharging fecal coliform into the streams for subwatershed Buttermilk. The table presents the existing fecal coliform load from cows in the stream, the allocated load, and the percent reduction.

Table B.21. Load allocations for Built-up, Farmstead, Forest, and Barren lands in the Buttermilk subwatershed

	Builtup loads (counts/month)		Farmstead loads (counts/month)		Forest loads (counts/month)		Barren loads (counts/month)	
Mon	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction
Jan	2.10E+08	0	9.16E+07	0	4.21E+08	0	3.71E+06	0
Feb	1.51E+08	0	6.56E+07	0	3.56E+08	0	2.83E+06	0
Mar	3.04E+08	0	1.32E+08	0	7.33E+08	0	5.67E+06	0
Apr	2.07E+08	0	8.92E+07	0	5.62E+08	0	4.16E+06	0
May	1.54E+08	0	6.79E+07	0	3.22E+08	0	2.37E+06	0
Jun	1.29E+08	0	5.75E+07	0	1.96E+08	0	1.59E+06	0
Jul	1.67E+08	0	7.46E+07	0	2.26E+08	0	1.99E+06	0
Aug	1.27E+08	0	5.57E+07	0	2.14E+08	0	1.94E+06	0
Sep	1.29E+08	0	5.89E+07	0	9.73E+07	0	9.81E+05	0
Oct	1.10E+08	0	4.77E+07	0	2.22E+08	0	1.95E+06	0
Nov	1.53E+08	0	6.77E+07	0	2.17E+08	0	2.21E+06	0
Dec	1.54E+08	0	6.76E+07	0	2.53E+08	0	2.49E+06	0
TOT	2.00E+09	0	8.76E+08	0	3.82E+09	0	3.19E+07	0

Table B.22. Load allocations for Cropland and Loafing Lots in the Buttermilk subwatershed

Mon	Cropland loads (counts/month)			Loafing lots loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	3.80E+08	3.65E+08	3.75	3.00E+10	6.10E+09	79.69
Feb	7.50E+08	6.68E+08	10.93	2.72E+10	5.04E+09	81.43
Mar	5.89E+09	5.09E+09	13.46	9.94E+10	1.91E+10	80.78
Apr	4.65E+09	3.34E+09	28.11	8.28E+10	1.39E+10	83.23
May	4.25E+08	4.00E+08	5.73	1.93E+10	3.57E+09	81.45
Jun	1.76E+08	1.63E+08	7.44	1.29E+10	1.91E+09	85.20
Jul	2.07E+08	1.99E+08	3.92	3.16E+10	5.81E+09	81.60
Aug	5.51E+08	4.82E+08	12.46	3.37E+10	6.43E+09	80.89
Sep	1.09E+08	1.06E+08	2.36	4.74E+08	7.01E+07	85.23
Oct	6.27E+08	5.62E+08	10.44	4.09E+10	9.91E+09	75.75
Nov	1.94E+08	1.56E+08	19.31	3.42E+10	5.34E+09	84.36
Dec	2.33E+08	2.26E+08	3.19	1.41E+10	3.13E+09	77.77
TOT	1.42E+10	1.18E+10	17.08	4.26E+11	8.03E+10	81.17

Table B.23. Load allocations for Pasture 1, Pasture 2, and Pasture 3 in the Buttermilk subwatershed

Mon	Pasture 1 loads (counts/month)			Pasture 2 loads (counts/month)			Pasture 3 loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	6.61E+09	3.88E+09	41.26	1.73E+09	9.79E+08	43.51	3.07E+10	1.75E+10	43.08
Feb	9.38E+09	5.44E+09	41.97	1.52E+09	8.70E+08	42.67	2.31E+10	1.32E+10	42.99
Mar	4.31E+10	2.52E+10	41.57	5.31E+09	3.15E+09	40.69	7.33E+10	4.29E+10	41.42
Apr	3.44E+10	1.67E+10	51.37	4.15E+09	2.05E+09	50.69	5.72E+10	2.78E+10	51.32
May	7.06E+09	4.14E+09	41.39	9.24E+08	5.36E+08	42.03	1.26E+10	7.15E+09	43.16
Jun	4.38E+09	2.13E+09	51.24	6.05E+08	2.79E+08	53.94	8.24E+09	3.74E+09	54.54
Jul	1.07E+10	6.08E+09	42.95	1.49E+09	8.24E+08	44.73	2.05E+10	1.13E+10	44.73
Aug	1.19E+10	6.92E+09	41.86	1.62E+09	9.13E+08	43.56	2.23E+10	1.26E+10	43.49
Sep	3.02E+08	2.12E+08	29.90	3.01E+07	1.89E+07	37.17	3.22E+08	1.62E+08	49.68
Oct	1.78E+10	1.16E+10	34.84	2.43E+09	1.59E+09	34.49	3.37E+10	2.19E+10	34.96
Nov	6.83E+09	3.31E+09	51.57	1.53E+09	7.20E+08	52.92	2.59E+10	1.23E+10	52.50
Dec	3.84E+09	2.28E+09	40.71	9.98E+08	5.67E+08	43.17	1.76E+10	1.01E+10	42.77
TOT	1.56E+11	8.80E+10	43.74	2.23E+10	1.25E+10	44.06	3.25E+11	1.81E+11	44.47

Table B.24. Allocations for fecal coliform loads from cows in the stream for the Buttermilk subwatershed

Month	Existing load (counts/month)	Allocated load (counts/month)	Percent reduction
January	1.55E+10	1.55E+10	0.0
February	1.40E+10	1.40E+10	0.0
March	2.55E+12	7.64E+10	97.0
April	5.39E+12	0.00E+00	100.0
May	5.57E+12	5.57E+10	99.0
June	8.08E+12	0.00E+00	100.0
July	8.35E+12	0.00E+00	100.0
August	8.35E+12	0.00E+00	100.0
September	5.39E+12	0.00E+00	100.0
October	5.57E+12	0.00E+00	100.0
November	2.46E+12	2.46E+10	99.0
December	1.55E+10	1.55E+10	0.0
TOTAL	5.17E+13	2.02E+11	99.6

B.2.6 War 1

Table B.25 presents the load allocations to Built-up, Farmstead and Forest lands in the War 1 subwatershed. Table B.26 contains the load allocations to Cropland and Loafing Lots, and Table B.27 contains the load allocations to the pasturelands (Pasture 1, Pasture 2, and Pasture 3) in the War 1 subwatershed.

Table B.28 presents the load allocations for loads from cows directly discharging fecal coliform into the streams for subwatershed War 1. The table presents the existing fecal coliform load from cows in the stream, the allocated load, and the percent reduction.

Table B.25. Load allocations for Built-up, Farmstead, and Forest lands in the War 1 subwatershed.

	Builtup loads (counts/month)		Farmstead loads (counts/month)		Forest loads (counts/month)	
Mon	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction
Jan	2.05E+08	0	2.71E+07	0	2.76E+09	0
Feb	1.47E+08	0	1.94E+07	0	2.34E+09	0
Mar	2.96E+08	0	3.90E+07	0	4.82E+09	0
Apr	1.87E+08	0	2.45E+07	0	3.42E+09	0
May	1.50E+08	0	2.01E+07	0	2.11E+09	0
Jun	1.29E+08	0	1.76E+07	0	1.21E+09	0
Jul	1.62E+08	0	2.21E+07	0	1.49E+09	0
Aug	1.23E+08	0	1.65E+07	0	1.40E+09	0
Sep	1.10E+08	0	1.53E+07	0	6.64E+08	0
Oct	1.07E+08	0	1.41E+07	0	1.46E+09	0
Nov	1.33E+08	0	1.79E+07	0	1.20E+09	0
Dec	1.50E+08	0	2.00E+07	0	1.66E+09	0
TOT	1.90E+09	0	2.54E+08	0	2.45E+10	0

Table B.26. Load allocations for Cropland in the War 1 subwatershed

Mon	Cropland loads (counts/month)		
	Existing	Allocated	Percent Reduction
Jan	9.47E+07	9.11E+07	3.74
Feb	1.87E+08	1.67E+08	10.95
Mar	1.47E+09	1.27E+09	13.68
Apr	9.53E+08	8.33E+08	12.62
May	1.06E+08	9.99E+07	5.63
Jun	4.14E+07	4.07E+07	1.72
Jul	5.16E+07	4.96E+07	3.94
Aug	1.37E+08	1.20E+08	12.36
Sep	2.71E+07	2.65E+07	2.27
Oct	1.57E+08	1.40E+08	10.65
Nov	4.10E+07	3.90E+07	4.88
Dec	5.83E+07	5.64E+07	3.25
TOT	3.32E+09	2.93E+09	11.80

Table B.27. Load allocations for Pasture 1, Pasture 2, and Pasture 3 in the War 1 subwatershed

Mon	Pasture 1 loads (counts/month)			Pasture 2 loads (counts/month)			Pasture 3 loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	1.60E+09	9.44E+08	41.21	6.26E+08	3.54E+08	43.48	3.03E+10	1.73E+10	43.02
Feb	2.27E+09	1.32E+09	41.84	5.49E+08	3.15E+08	42.72	2.28E+10	1.30E+10	43.09
Mar	1.05E+10	6.12E+09	41.49	1.92E+09	1.14E+09	40.66	7.22E+10	4.23E+10	41.44
Apr	6.79E+09	4.05E+09	40.33	1.22E+09	7.41E+08	39.24	4.59E+10	2.74E+10	40.22
May	1.71E+09	1.00E+09	41.40	3.35E+08	1.94E+08	42.16	1.24E+10	7.03E+09	43.31
Jun	8.95E+08	5.18E+08	42.11	1.83E+08	1.01E+08	44.89	6.78E+09	3.68E+09	45.65
Jul	2.59E+09	1.48E+09	42.79	5.39E+08	2.98E+08	44.79	2.02E+10	1.12E+10	44.72
Aug	2.89E+09	1.68E+09	41.98	5.85E+08	3.30E+08	43.70	2.20E+10	1.24E+10	43.49
Sep	6.67E+07	5.14E+07	22.99	9.60E+06	6.85E+06	28.67	2.65E+08	1.59E+08	39.78
Oct	4.32E+09	2.81E+09	34.89	8.81E+08	5.76E+08	34.66	3.32E+10	2.17E+10	34.77
Nov	1.33E+09	8.01E+08	39.92	4.43E+08	2.60E+08	41.42	2.04E+10	1.21E+10	40.73
Dec	9.33E+08	5.52E+08	40.83	3.61E+08	2.05E+08	43.22	1.74E+10	9.94E+09	42.80
TOT	3.59E+10	2.13E+10	40.52	7.65E+09	4.52E+09	40.96	3.04E+11	1.78E+11	41.37

Table B.28. Allocations for fecal coliform loads from cows in the stream for the War 1 subwatershed

Month	Existing load (counts/month)	Allocated load (counts/month)	Percent reduction
January	5.98E+09	5.98E+09	0.0
February	5.40E+09	5.40E+09	0.0
March	9.61E+11	9.61E+10	90.0
April	2.03E+12	8.12E+10	96.0
May	2.10E+12	1.05E+11	95.0
June	3.05E+12	9.14E+10	97.0
July	3.15E+12	6.30E+10	98.0
August	3.15E+12	3.15E+10	99.0
September	2.03E+12	4.06E+10	98.0
October	2.10E+12	6.30E+10	97.0
November	9.30E+11	3.72E+10	96.0
December	5.98E+09	5.98E+09	0.0
TOTAL	1.95E+13	6.26E+11	96.8

B.2.7 Muddy 1

Table B.29 presents the load allocations to Built-up, Farmstead and Forest lands in the Muddy 1 subwatershed. Table B.30 contains the load allocations to Cropland and Loafing Lots, and Table B.31 contains the load allocations to the pasturelands (Pasture 1, Pasture 2, and Pasture 3) in the Muddy 1 subwatershed.

Table B.32 presents the load allocations for loads from cows directly discharging fecal coliform into the streams for subwatershed Muddy 1. The table presents the existing fecal coliform load from cows in the stream, the allocated load, and the percent reduction.

Table B.29. Load allocations for Built-up, Farmstead, and Forest lands in the Muddy 1 subwatershed.

	Builtup loads (counts/month)		Farmstead loads (counts/month)		Forest loads (counts/month)	
Mon	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction
Jan	5.66E+08	0	3.50E+08	0	1.56E+09	0
Feb	4.08E+08	0	2.51E+08	0	1.32E+09	0
Mar	8.19E+08	0	5.04E+08	0	2.73E+09	0
Apr	5.17E+08	0	3.16E+08	0	1.94E+09	0
May	4.15E+08	0	2.60E+08	0	1.20E+09	0
Jun	3.57E+08	0	2.28E+08	0	6.85E+08	0
Jul	4.49E+08	0	2.86E+08	0	8.43E+08	0
Aug	3.41E+08	0	2.13E+08	0	7.95E+08	0
Sep	3.06E+08	0	1.97E+08	0	3.76E+08	0
Oct	2.95E+08	0	1.82E+08	0	8.27E+08	0
Nov	3.67E+08	0	2.32E+08	0	6.81E+08	0
Dec	4.15E+08	0	2.59E+08	0	9.40E+08	0
TOT	5.26E+09	0	3.28E+09	0	1.39E+10	0

Table B.30. Load allocations for Cropland and Loafing Lots in the Muddy 1 subwatershed.

Mon	Cropland loads (counts/month)			Loafing lots loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	1.23E+09	1.19E+09	3.73	2.58E+10	5.23E+09	79.72
Feb	2.44E+09	2.17E+09	10.95	2.33E+10	4.33E+09	81.45
Mar	1.92E+10	1.66E+10	13.62	8.53E+10	1.64E+10	80.76
Apr	1.25E+10	1.09E+10	12.66	5.79E+10	1.19E+10	79.37
May	1.38E+09	1.30E+09	5.83	1.66E+10	3.07E+09	81.47
Jun	5.40E+08	5.31E+08	1.73	9.25E+09	1.64E+09	82.28
Jul	6.74E+08	6.47E+08	3.98	2.72E+10	4.99E+09	81.63
Aug	1.79E+09	1.57E+09	12.34	2.89E+10	5.53E+09	80.86
Sep	3.54E+08	3.46E+08	2.29	3.32E+08	6.02E+07	81.86
Oct	2.04E+09	1.83E+09	10.63	3.51E+10	8.49E+09	75.78
Nov	5.35E+08	5.09E+08	4.85	2.35E+10	4.60E+09	80.43
Dec	7.60E+08	7.35E+08	3.17	1.21E+10	2.69E+09	77.78
TOT	4.34E+10	3.83E+10	11.79	3.45E+11	6.90E+10	80.02

Table B.31. Load allocations for Pasture 1, Pasture 2, and Pasture 3 in the Muddy 1 subwatershed

Mon	Pasture 1 loads (counts/month)			Pasture 2 loads (counts/month)			Pasture 3 loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	1.85E+10	1.09E+10	41.26	2.96E+09	1.67E+09	43.59	7.01E+10	3.99E+10	43.11
Feb	2.62E+10	1.52E+10	41.95	2.59E+09	1.49E+09	42.70	5.26E+10	3.00E+10	43.09
Mar	1.21E+11	7.06E+10	41.58	9.08E+09	5.38E+09	40.70	1.67E+11	9.78E+10	41.42
Apr	7.84E+10	4.68E+10	40.25	5.76E+09	3.50E+09	39.27	1.06E+11	6.34E+10	40.13
May	1.98E+10	1.16E+10	41.41	1.58E+09	9.16E+08	42.07	2.87E+10	1.63E+10	43.38
Jun	1.03E+10	5.98E+09	41.99	8.64E+08	4.76E+08	44.84	1.56E+10	8.54E+09	45.41
Jul	2.98E+10	1.71E+10	42.83	2.55E+09	1.41E+09	44.79	4.68E+10	2.59E+10	44.66
Aug	3.34E+10	1.94E+10	42.04	2.76E+09	1.56E+09	43.55	5.08E+10	2.88E+10	43.33
Sep	7.70E+08	5.93E+08	23.01	4.53E+07	3.23E+07	28.65	6.12E+08	3.69E+08	39.75
Oct	5.00E+10	3.25E+10	35.08	4.16E+09	2.71E+09	34.73	7.68E+10	4.99E+10	34.96
Nov	1.54E+10	9.25E+09	39.85	2.10E+09	1.23E+09	41.32	4.72E+10	2.80E+10	40.67
Dec	1.08E+10	6.38E+09	40.69	1.71E+09	9.69E+08	43.19	4.02E+10	2.30E+10	42.74
TOT	4.14E+11	2.46E+11	40.56	3.61E+10	2.13E+10	40.97	7.02E+11	4.12E+11	41.36

Table B.32. Allocations for fecal coliform loads from cows in the stream for the Muddy 1 subwatershed

Month	Existing load (counts/month)	Allocated load (counts/month)	Percent reduction
January	4.11E+10	4.11E+10	0.0
February	3.71E+10	3.71E+10	0.0
March	6.67E+12	2.67E+11	96.0
April	1.41E+13	0.00E+00	100.0
May	1.46E+13	1.46E+11	99.0
June	2.11E+13	0.00E+00	100.0
July	2.18E+13	0.00E+00	100.0
August	2.18E+13	0.00E+00	100.0
September	1.41E+13	0.00E+00	100.0
October	1.46E+13	0.00E+00	100.0
November	6.45E+12	6.45E+10	99.0
December	4.11E+10	4.11E+10	0.0
TOTAL	1.35E+14	5.96E+11	99.6

B.2.8 Patterson

Table B.33 presents the load allocations to Built-up, Farmstead, and Forest lands in the Patterson subwatershed. Table B.34 contains the load allocations to Cropland and Loafing Lots, and Table B.35 contains the load allocations to the pasturelands (Pasture 1, Pasture 2, and Pasture 3) in the Patterson subwatershed.

Table B.36 presents the load allocations for loads from cows directly discharging fecal coliform into the streams for subwatershed Muddy 2. The table presents the existing fecal coliform load from cows in the stream, the allocated load, and the percent reduction.

Table B.33. Load allocations for Built-up, Farmstead, Forest, and Barren lands in the Patterson subwatershed

	Builtup loads (counts/month)		Farmstead loads (counts/month)		Forest loads (counts/month)		Barren loads (counts/month)	
Mon	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction	Existing and Allocated	Percent Reduction
Jan	1.53E+07	0	8.70E+06	0	2.08E+09	0	1.20E+07	0
Feb	1.11E+07	0	6.24E+06	0	1.76E+09	0	9.16E+06	0
Mar	2.22E+07	0	1.25E+07	0	3.62E+09	0	1.83E+07	0
Apr	1.40E+07	0	7.87E+06	0	2.57E+09	0	1.24E+07	0
May	1.12E+07	0	6.43E+06	0	1.59E+09	0	7.68E+06	0
Jun	9.62E+06	0	5.61E+06	0	9.10E+08	0	4.80E+06	0
Jul	1.21E+07	0	7.04E+06	0	1.12E+09	0	6.44E+06	0
Aug	9.21E+06	0	5.28E+06	0	1.05E+09	0	6.26E+06	0
Sep	8.22E+06	0	4.85E+06	0	4.99E+08	0	3.12E+06	0
Oct	8.00E+06	0	4.53E+06	0	1.10E+09	0	6.33E+06	0
Nov	9.92E+06	0	5.72E+06	0	9.04E+08	0	5.97E+06	0
Dec	1.12E+07	0	6.41E+06	0	1.25E+09	0	8.05E+06	0
TOT	1.42E+08	0	8.12E+07	0	1.85E+10	0	1.01E+08	0

Table B.34. Load allocations for Cropland in the Patterson subwatershed

Mon	Cropland loads (counts/month)		
	Existing	Allocated	Percent Reduction
Jan	4.20E+07	4.04E+07	3.75
Feb	8.29E+07	7.38E+07	11.01
Mar	6.51E+08	5.63E+08	13.54
Apr	4.23E+08	3.69E+08	12.79
May	4.69E+07	4.42E+07	5.73
Jun	1.84E+07	1.80E+07	1.71
Jul	2.29E+07	2.20E+07	3.97
Aug	6.10E+07	5.33E+07	12.52
Sep	1.20E+07	1.18E+07	2.33
Oct	6.94E+07	6.20E+07	10.65
Nov	1.82E+07	1.73E+07	4.84
Dec	2.58E+07	2.50E+07	3.20
TOT	1.47E+09	1.30E+09	11.80

Table B.35. Load allocations for Pasture 1, Pasture 2, and Pasture 3 in the Patterson subwatershed

Mon	Pasture 1 loads (counts/month)			Pasture 2 loads (counts/month)			Pasture 3 loads (counts/month)		
	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction	Existing	Allocated	Percent Reduction
Jan	6.20E+08	3.64E+08	41.33	1.43E+09	8.07E+08	43.54	6.28E+08	3.57E+08	43.05
Feb	8.79E+08	5.10E+08	42.04	1.25E+09	7.15E+08	42.79	4.72E+08	2.69E+08	43.10
Mar	4.04E+09	2.36E+09	41.53	4.37E+09	2.59E+09	40.68	1.50E+09	8.76E+08	41.51
Apr	2.62E+09	1.57E+09	40.22	2.78E+09	1.69E+09	39.25	9.48E+08	5.69E+08	39.98
May	6.60E+08	3.87E+08	41.33	7.63E+08	4.42E+08	41.99	2.56E+08	1.46E+08	43.08
Jun	3.46E+08	2.00E+08	42.27	4.16E+08	2.30E+08	44.74	1.40E+08	7.64E+07	45.46
Jul	9.98E+08	5.70E+08	42.89	1.23E+09	6.79E+08	44.78	4.19E+08	2.32E+08	44.67
Aug	1.12E+09	6.48E+08	42.01	1.33E+09	7.53E+08	43.48	4.56E+08	2.57E+08	43.56
Sep	2.58E+07	1.98E+07	23.00	2.19E+07	1.56E+07	28.65	5.48E+06	3.30E+06	39.76
Oct	1.67E+09	1.09E+09	34.87	2.01E+09	1.31E+09	34.74	6.88E+08	4.48E+08	34.83
Nov	5.15E+08	3.09E+08	39.94	1.01E+09	5.93E+08	41.34	4.24E+08	2.50E+08	40.90
Dec	3.60E+08	2.13E+08	40.67	8.22E+08	4.66E+08	43.31	3.60E+08	2.06E+08	42.79
TOT	1.39E+10	8.24E+09	40.53	1.74E+10	1.03E+10	40.96	6.29E+09	3.69E+09	41.36

Table B.36. Allocations for fecal coliform loads from cows in the stream for the Patterson subwatershed

Month	Existing load (counts/month)	Allocated load (counts/month)	Percent reduction
January	1.76E+09	1.76E+09	0.0
February	1.59E+09	1.59E+09	0.0
March	2.99E+11	1.20E+11	60.0
April	6.32E+11	3.16E+10	95.0
May	6.53E+11	6.53E+10	90.0
June	9.48E+11	4.74E+10	95.0
July	9.79E+11	4.90E+10	95.0
August	9.79E+11	2.94E+10	97.0
September	6.32E+11	2.53E+10	96.0
October	6.53E+11	3.26E+10	95.0
November	2.89E+11	2.89E+10	90.0
December	1.76E+09	1.76E+09	0.0
TOTAL	6.07E+12	4.34E+11	92.8

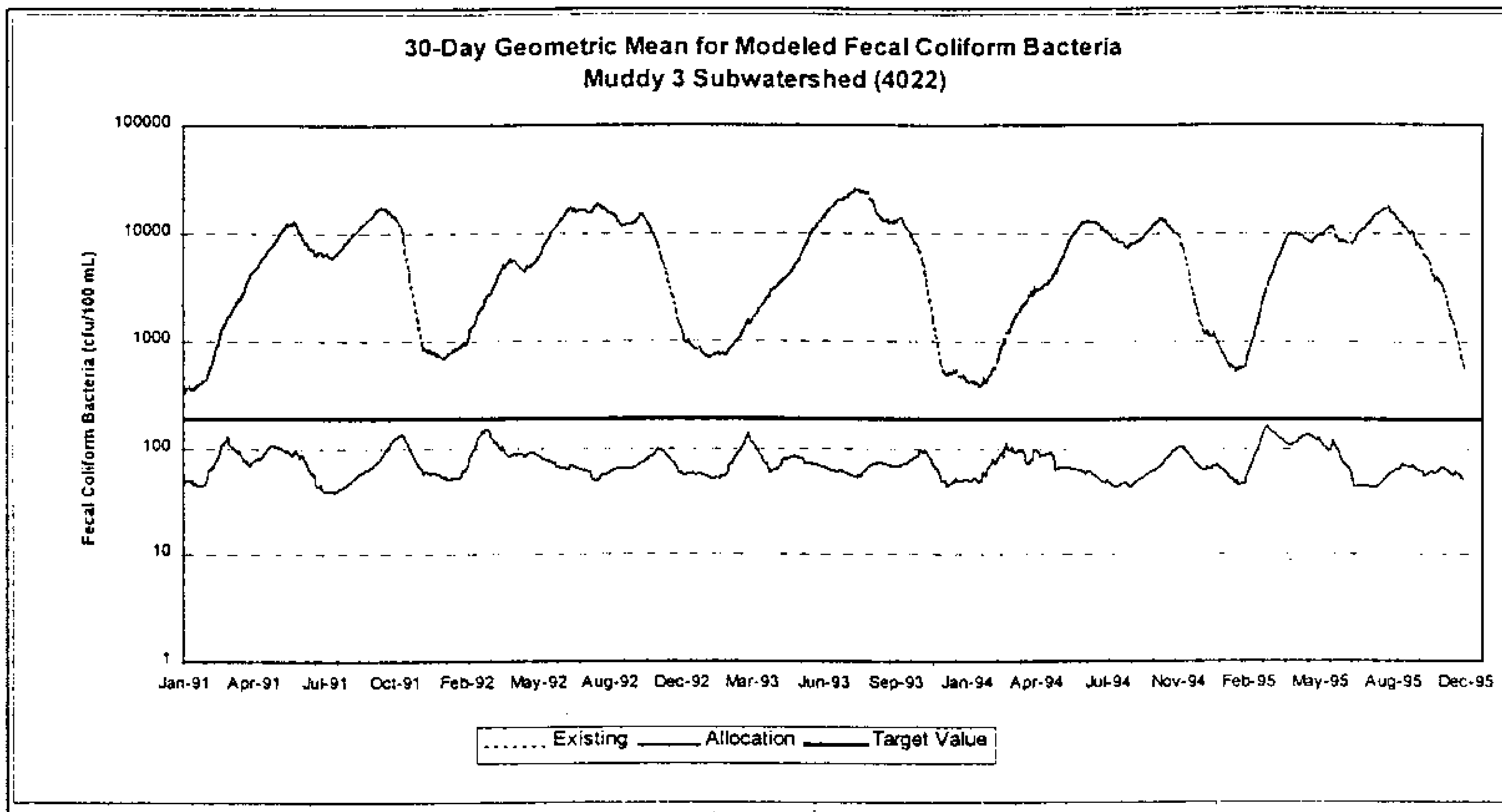


Figure B.1 Fecal coliform concentrations under modeled existing and allocation conditions for Muddy 3 subwatershed

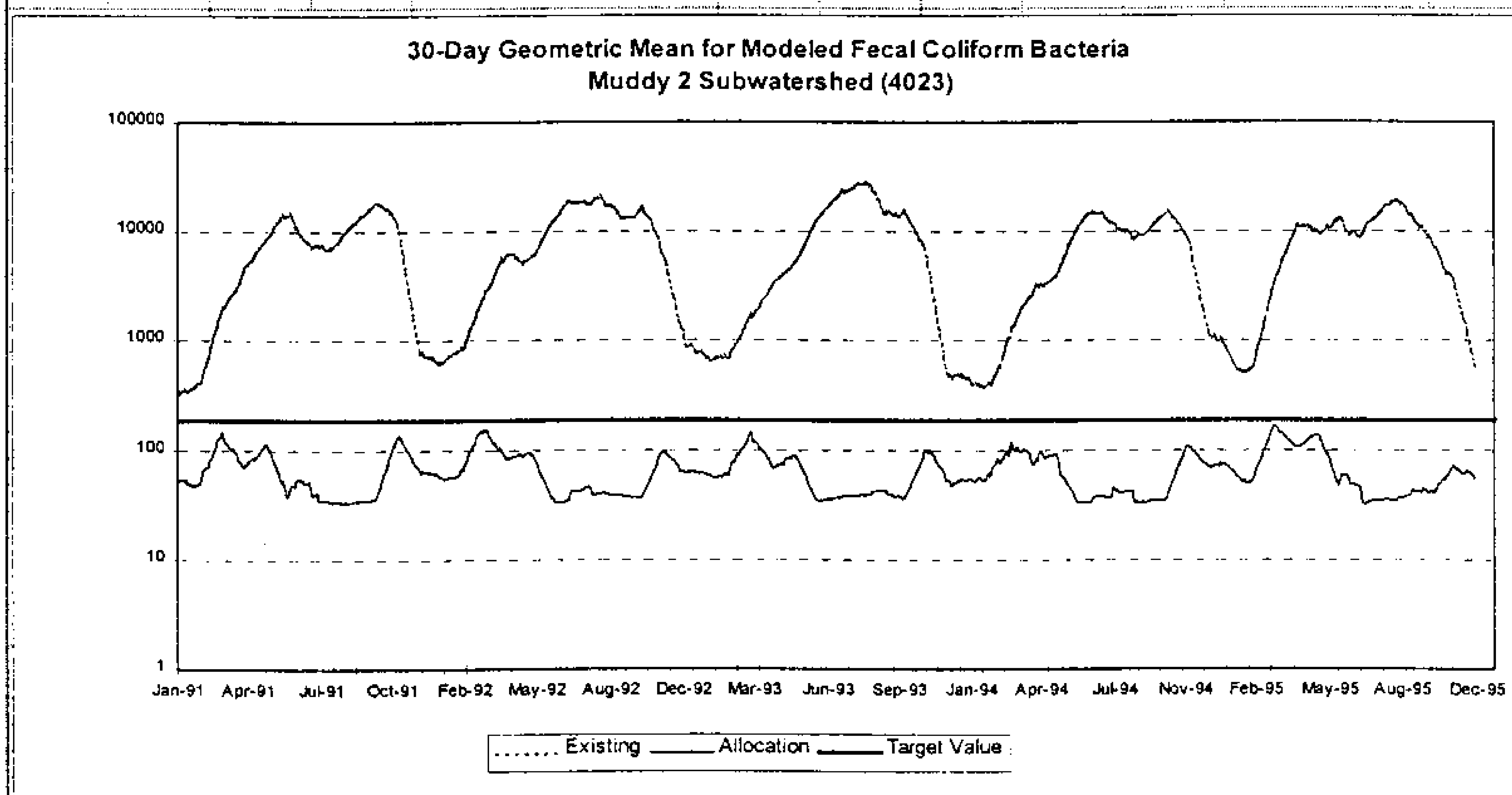


Figure B.2. Fecal coliform concentrations under modeled existing and allocation conditions for Muddy 2 subwatershed

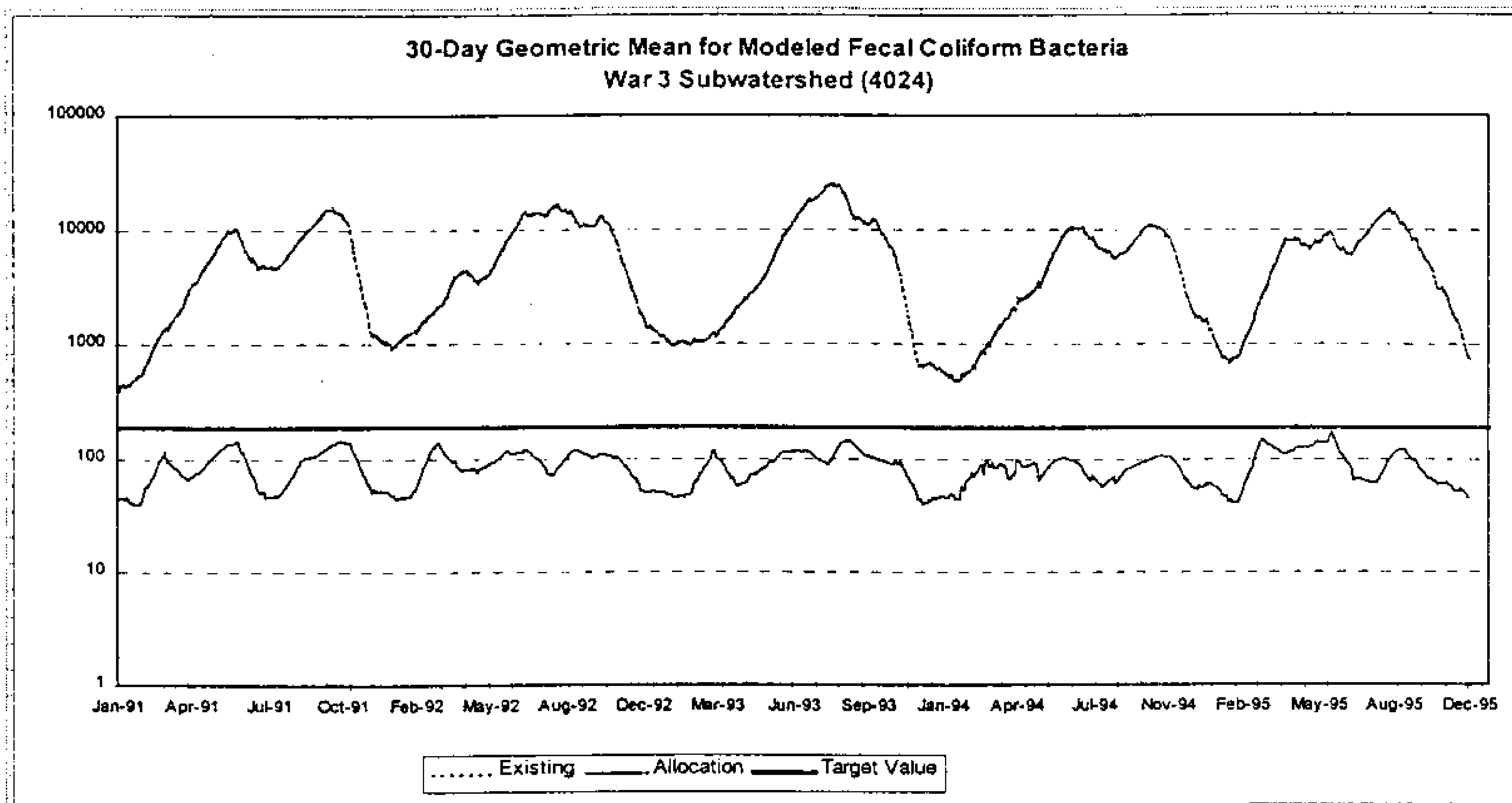


Figure B.3. Fecal coliform concentrations under modeled existing and allocation conditions for War 3 subwatershed

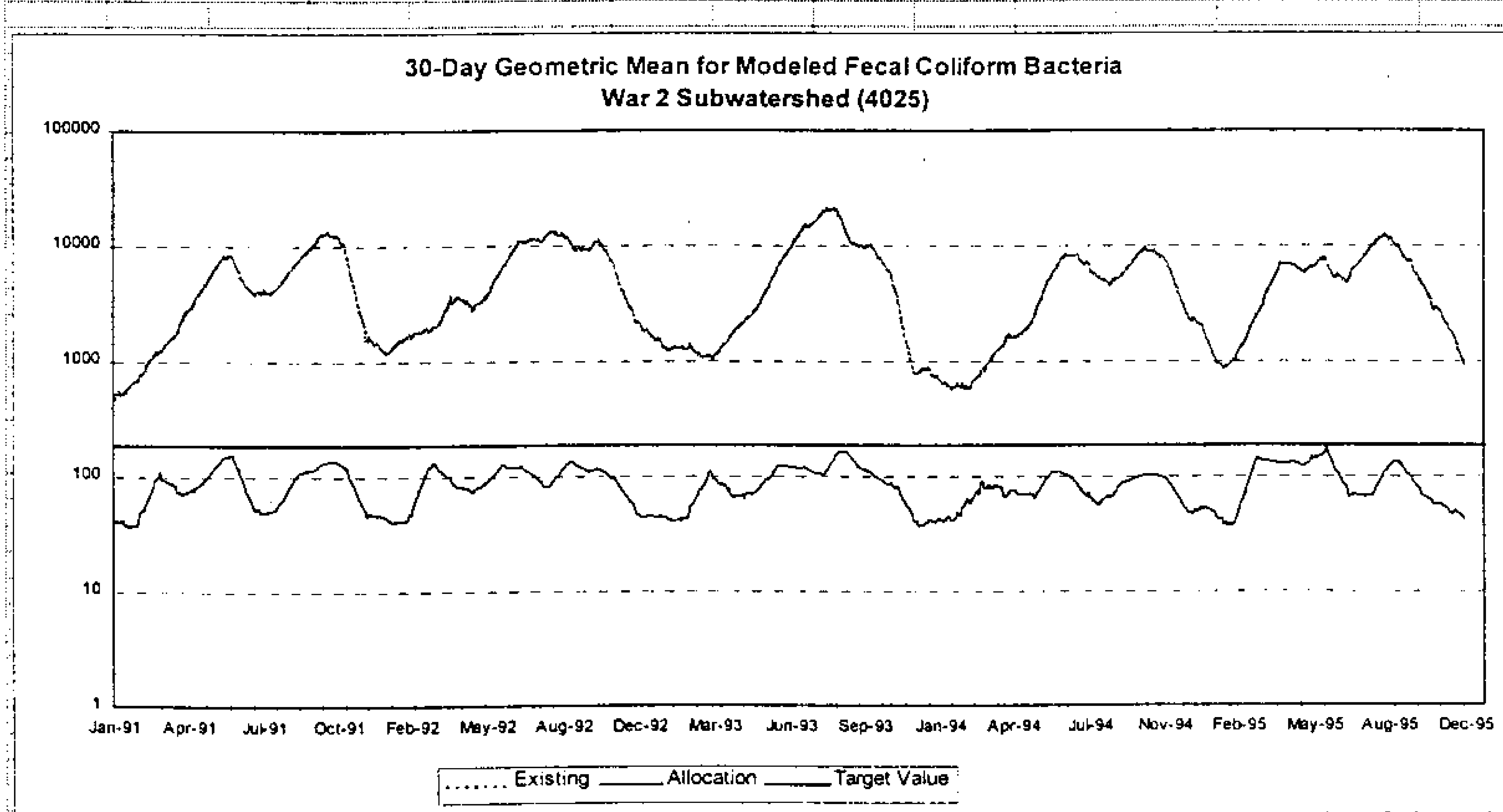


Figure B.4 Fecal coliform concentrations under modeled existing and allocation conditionsf for War 2 subwatershed

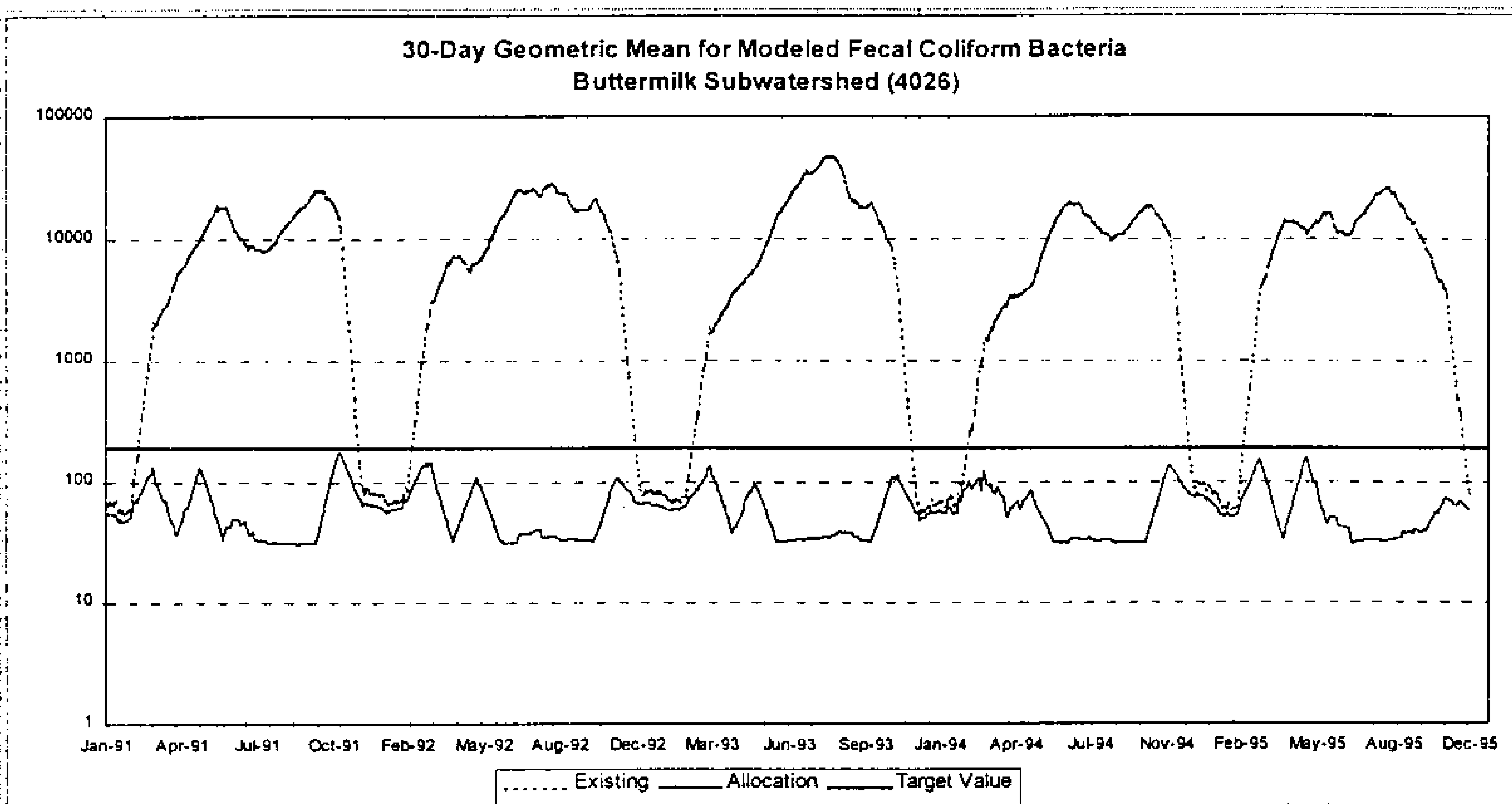


Figure B.5. Fecal coliform concentrations under modeled existing and allocation conditions for Buttermilk subwatershed

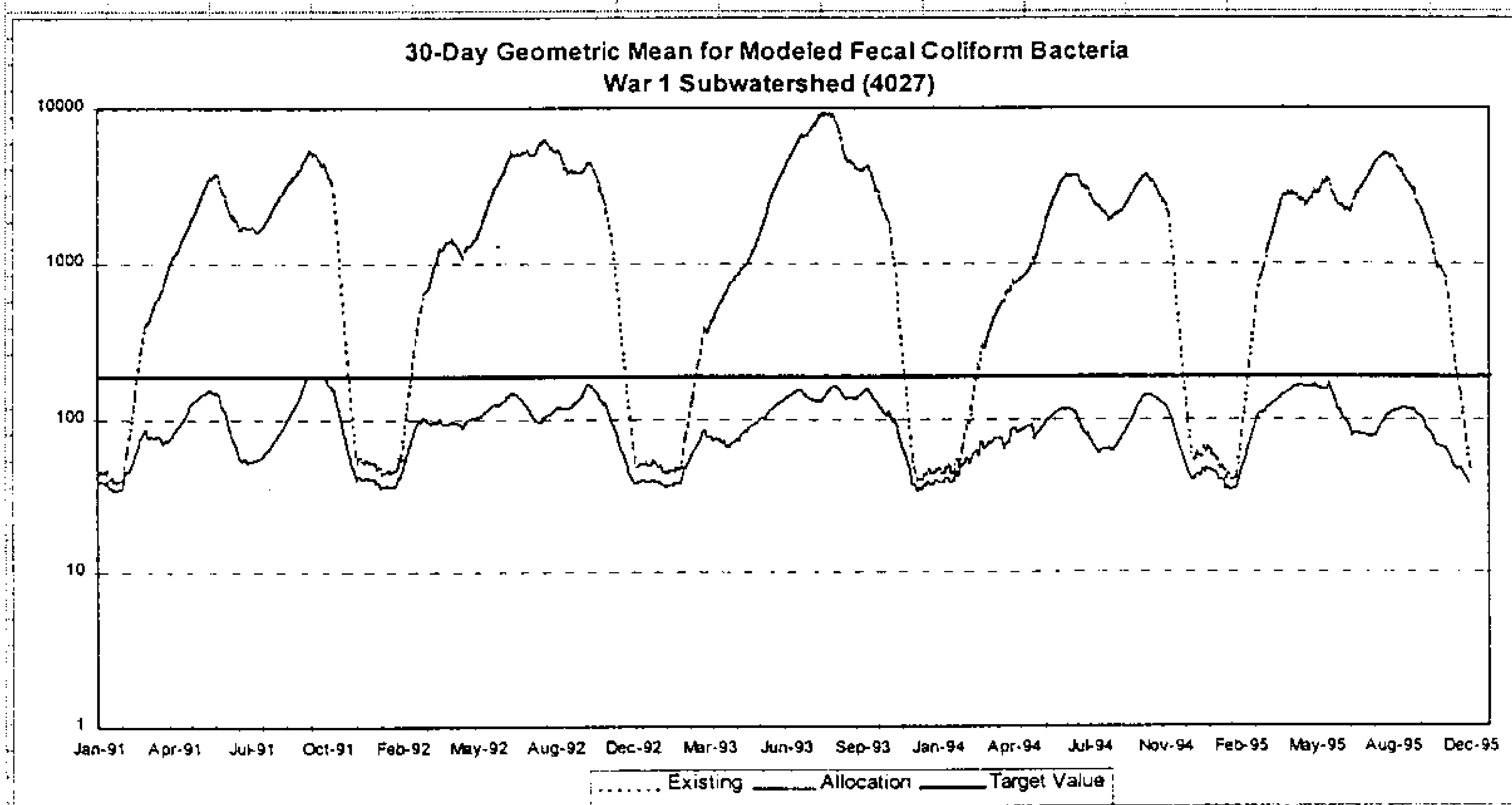


Figure B.6. Fecal coliform concentrations under modeled existing and allocation conditions for War 1 subwatershed

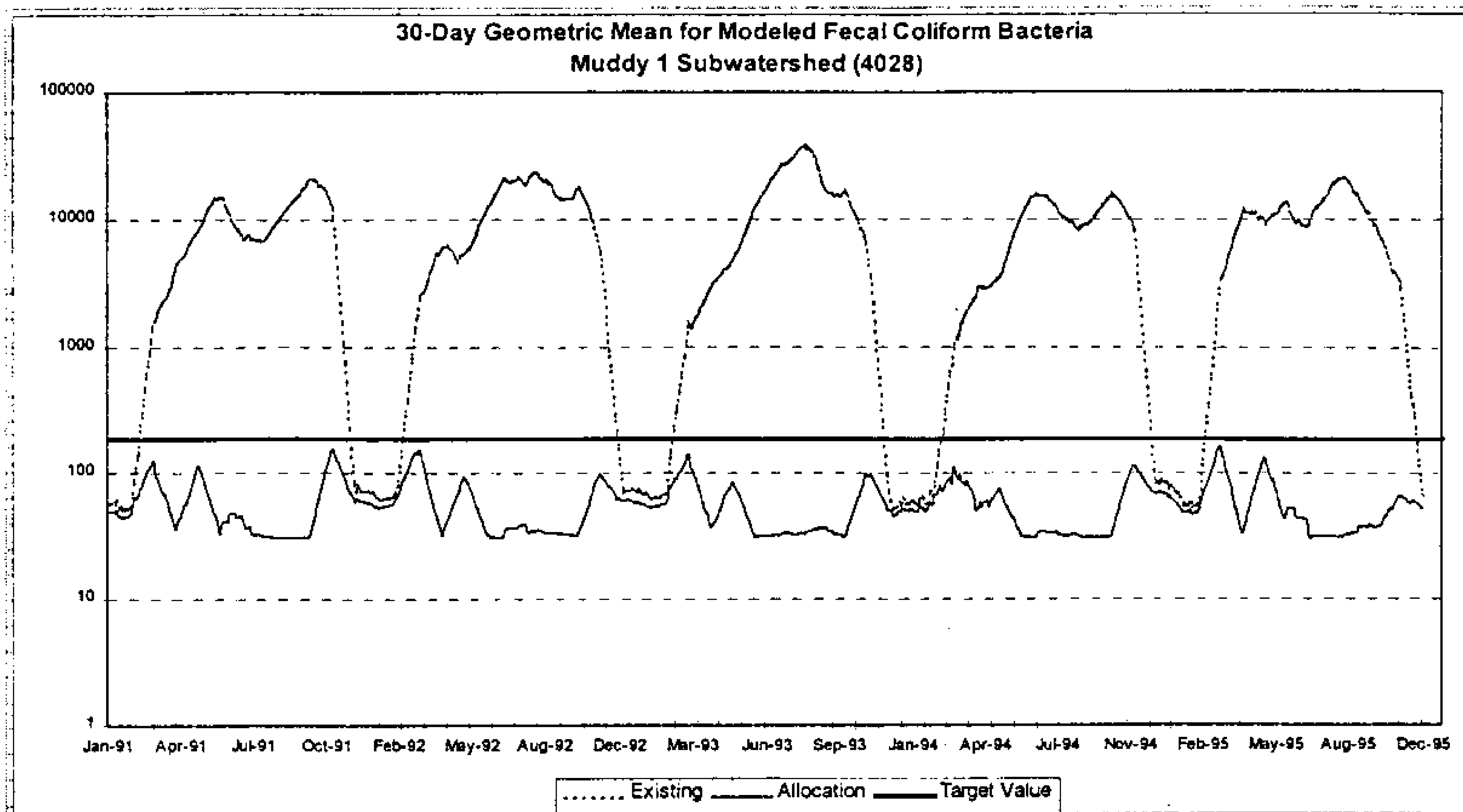
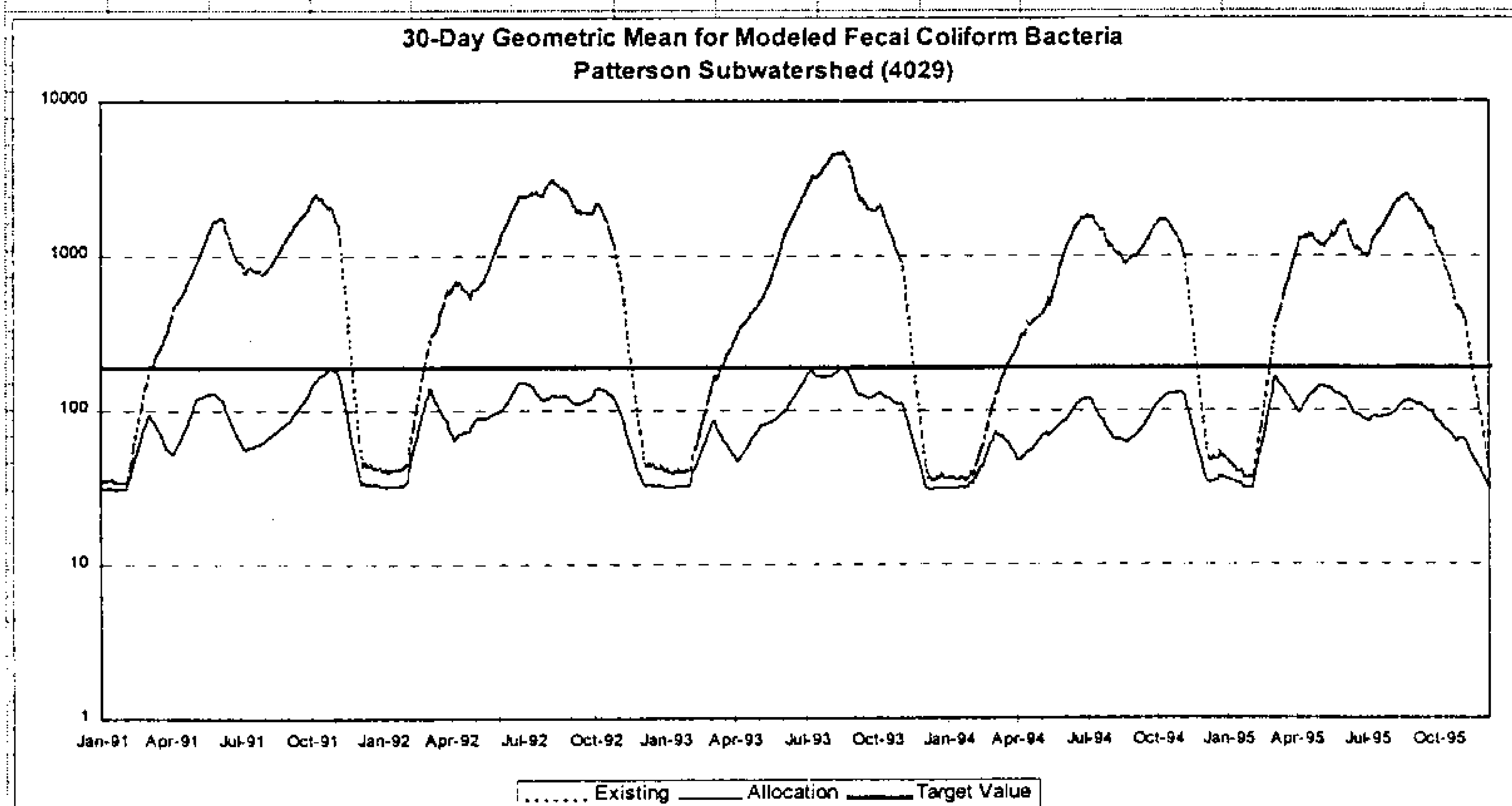


Figure B.7. Fecal coliform concentrations under modeled existing and allocation conditions for Muddy 1 subwatershed



APPENDIX C

Revalidation of the Fecal Coliform Bacteria Total Maximum Daily Load (TMDL) for the Muddy Creek Watershed in Virginia

Project Duration: May 15, 2000 - August 31, 2000

The objective of this study is to revalidate the coliform TMDL allocations for Muddy Creek, Virginia, using permitted levels for the waste load allocations (WLA). The original coliform TMDL utilized the observed current loads for the WLA.

C.1 Modeling Analysis

Details of the permitted coliform load from the WFI facility in the Muddy Creek watershed were obtained from Rod Bodkin (DEQ, Harrisonburg). Their permit specifies a monthly average concentration of 200 colony-forming units (cfu)/100 ml, and a weekly maximum of 400 cfu/100 ml.

No load for the Mount Clinton Elementary was included in this analysis. Not only has the school never discharged, but when the permit was reissued, the discharge limit for fecal coliform was set as zero. Thus, no load allocation need be reserved for the school.

With the assistance of the EPA, we obtained the necessary BASINS files to simulate coliform levels in Muddy Creek for both the current conditions and after allocations are made. Files were transferred from Tetra Tech, Inc., via Peter Gold (EPA), in June 2000, plus files previously acquired, were utilized.

Before incorporating any modifications to change WLA to permitted level, the modeling results were verified against the results of the fecal coliform TMDL study (MCTEW July 1999). Output files from the TMDL study were included in the files obtained through Peter Gold. The output of daily coliform counts in this revalidation study is the same as in the TMDL output files to the order of significant digits used.

In development of the TMDL, these daily coliform levels are converted to the 30-day geometric mean values. The final report of the coliform TMDL (MCTEW July 1999) includes graphs of the 30-day geometric mean coliform counts for a representative location from each sub-watershed in the Muddy Creek area. Although the daily values are the same, our graphs of the 30-day geometric mean are not exactly the same as shown in the TMDL report. Many of the graphs from the previous study include low points in the geometric mean, which do not appear consistent with the daily values. Possibly a zero value was inadvertently averaged in during the previous study. In some cases, these graphical errors did affect the estimates of the peak coliform level in a reach. Thus in the following results section, peak 30-day geometric means are the corrected values for the TMDL study. As will be shown, we do not feel that the graphical errors in the previous work have any significant impact on the conclusions or recommendations of that study or this revalidation study.

In the coliform TMDL, the WFI load was simulated using a steady-state load equal to the observed average monthly load. We have increased this load, assuming that WFI continuously discharged at its maximum permitted monthly concentration of coliform bacteria (200 cfu/ml). Thus the permitted WFI coliform load is more than 3.5 times the load that was used during the TMDL development. Furthermore, assuming that the WFI continuously discharges at its maximum permitted level conservatively assumes an upper bound on the point source coliform load. The resulting in-stream fecal coliform levels were then re-simulated using the TMDL allocation and the maximum permitted WFI load. We will simply refer to the results using the TMDL allocations in conjunction with the maximum permitted point source load as the "permitted load results." In the following section, the permitted load results are compared to the coliform bacteria goals.

C.2 Results for the Permitted Load Simulations

Using the original TMDL allocations or the permitted load simulations, the maximum 30-day geometric mean for all sub-watersheds is below 200 cfu/100 ml (Table 1). This is consistent with page 5-2 of the final fecal coliform report (MCTEW July 1999) that states "The allocation scenario for Muddy Creek was designed to meet the water quality standard of a geometric mean of 200 counts/100 ml with 0% exceedances." Given the conservative assumptions in the TMDL analysis, plus the assumption of the maximum point-source concentration, an implied margin of safety (MOS) is included in these estimates.

In addition to the implicit MOS, an explicit 5% margin of safety would also be preferred. A 5% explicit MOS would reduce the peak concentrations to a 30-day geometric mean of 190 cfu/100 ml. Note that neither the original TMDL allocations nor the permitted load simulations maintain the 5% explicit MOS at all times (Table 1). Furthermore, note that only two of the subwatersheds are at or below the WFI discharge point. Thus six of the subwatersheds are unaffected by changes in the WFI load. For the two downstream subwatersheds, the magnitude of change in the peak concentration is not great. For the Muddy 3 subwatershed, which includes Station #4, the peak 30-day geometric mean increases from 186 cfu/100 ml to 192 cfu/100 ml, while for the Muddy 2 subwatershed, the peak 30-day geometric mean increases from 178 cfu/100 ml to 190 cfu/100 ml. Although the explicit 5% MOS is not maintained at all time, Figures 1-8 demonstrate that violations of the explicit 5% MOS are fairly rare throughout the watershed. Violations of the explict 5% (concentrations greater than 190 cfu/100 ml but still less than 200 cfu/100 ml) typically occur less than once a year.

Table 1. Comparison of the simulated maximum 30-day geometric mean fecal coliform level using the TMDL allocations and using the permitted waste load allocations.

Sub-Watershed		Maximum 30-day Geometric Mean	
No.	Name	TMDL allocations	(Permitted WLA)
1	Muddy 3 (St. 4)	185.69	192.19
2	Muddy 2	178.36	190.05
3	Muddy 1	199.93	199.93
4	Patterson	199.43	199.43
5	Buttermilk	194.69	194.69
6	War 3	195.22	195.22
7	War 2	196.99	196.99
8	War 1	188.77	188.77

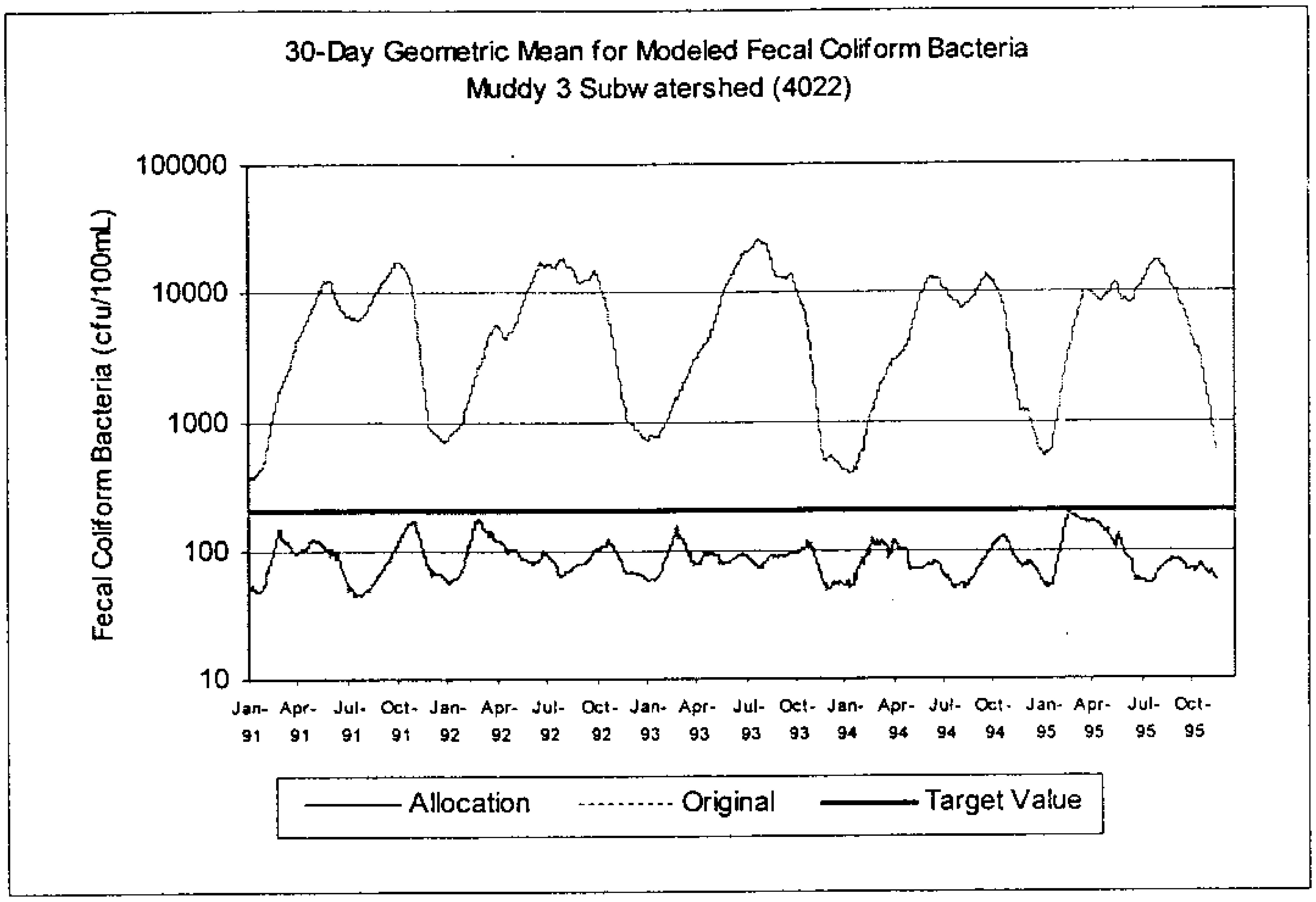


Figure 1. Fecal coliform concentrations under modeled existing and permitted load allocations for Muddy 3 sub-watershed.

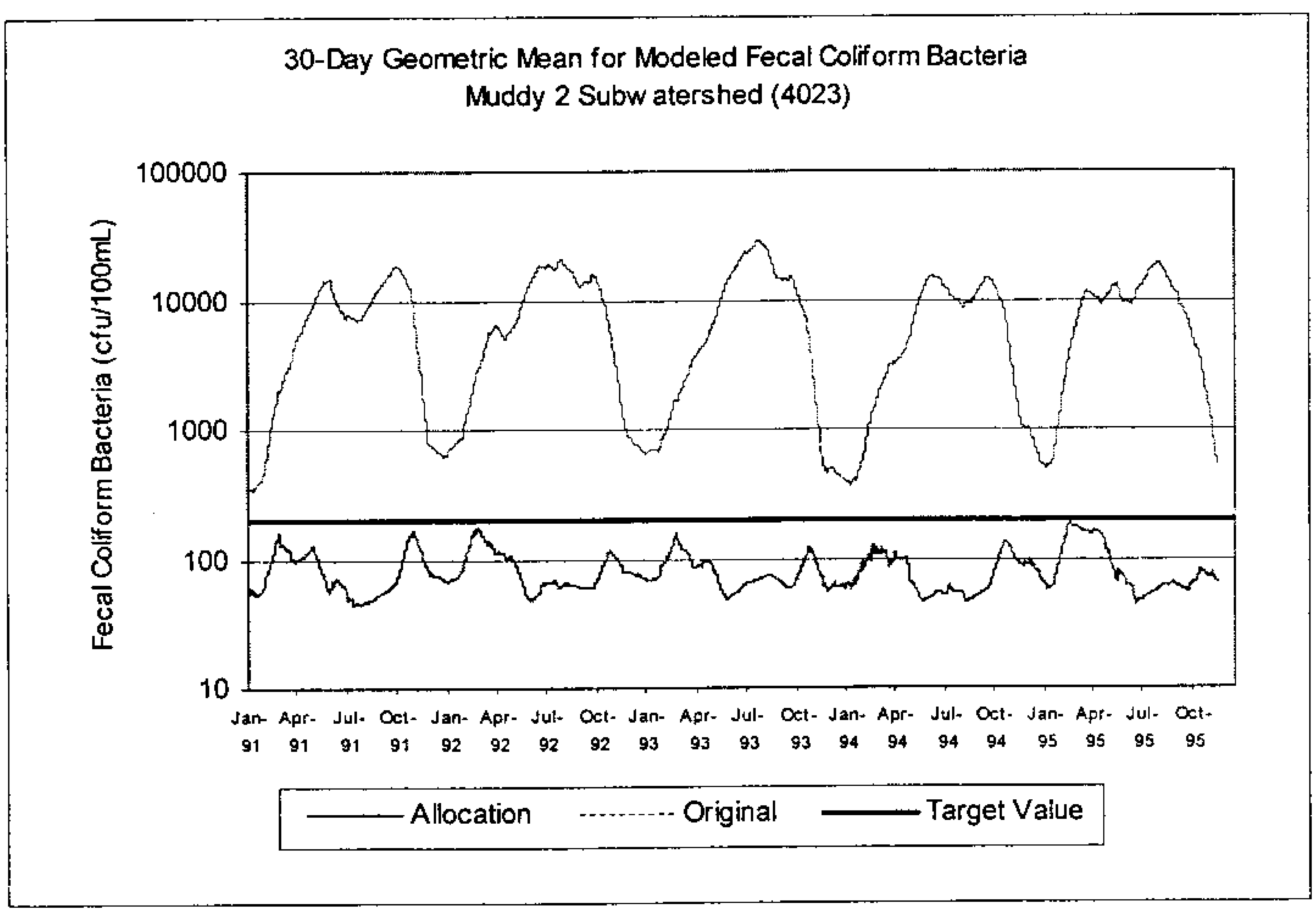


Figure 2. Fecal coliform concentrations under modeled existing and permitted load allocation conditions for Muddy 2 sub-watershed

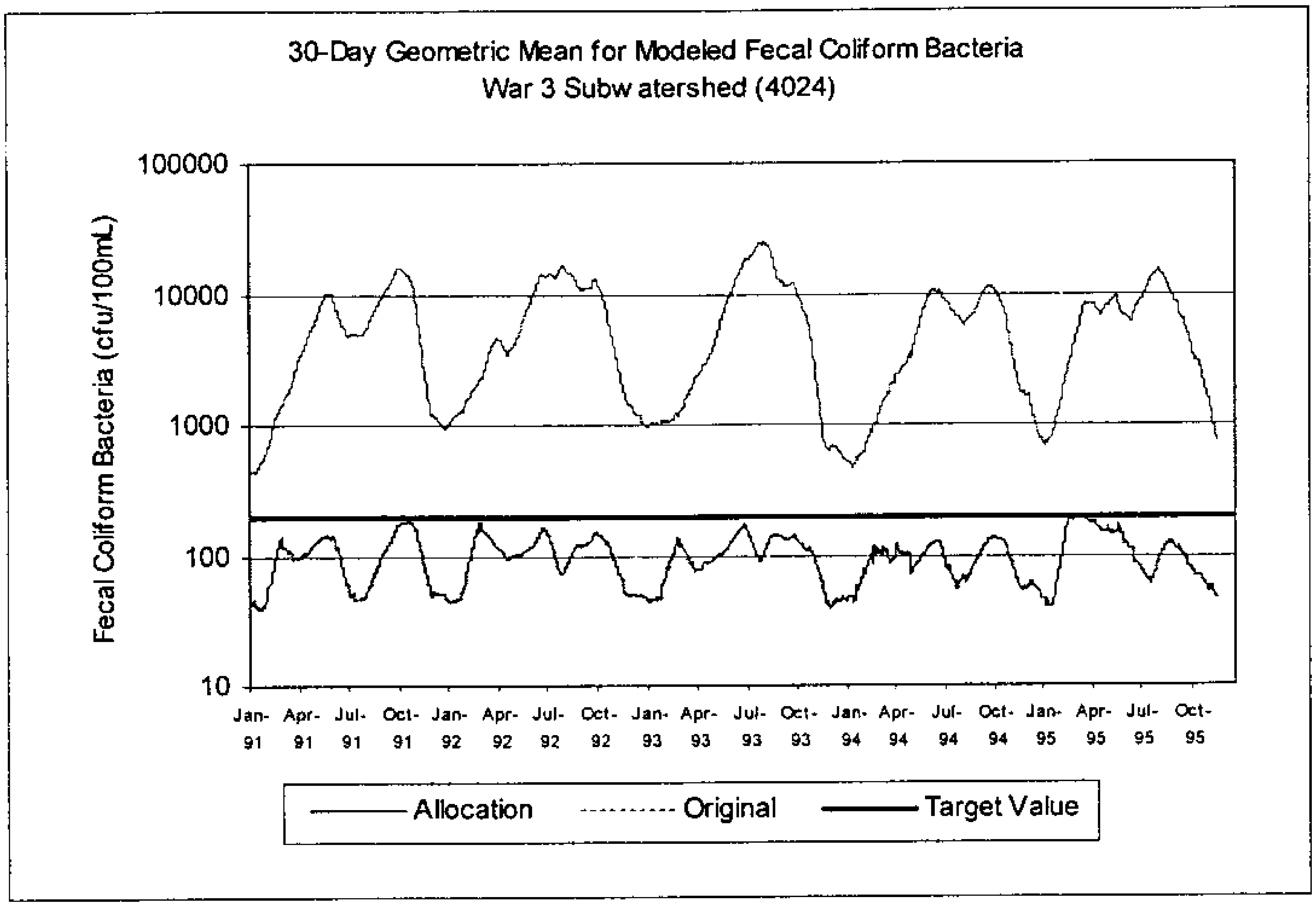


Figure 3. Fecal coliform concentrations under modeled existing and permitted load allocation conditions for War 3 sub-watershed

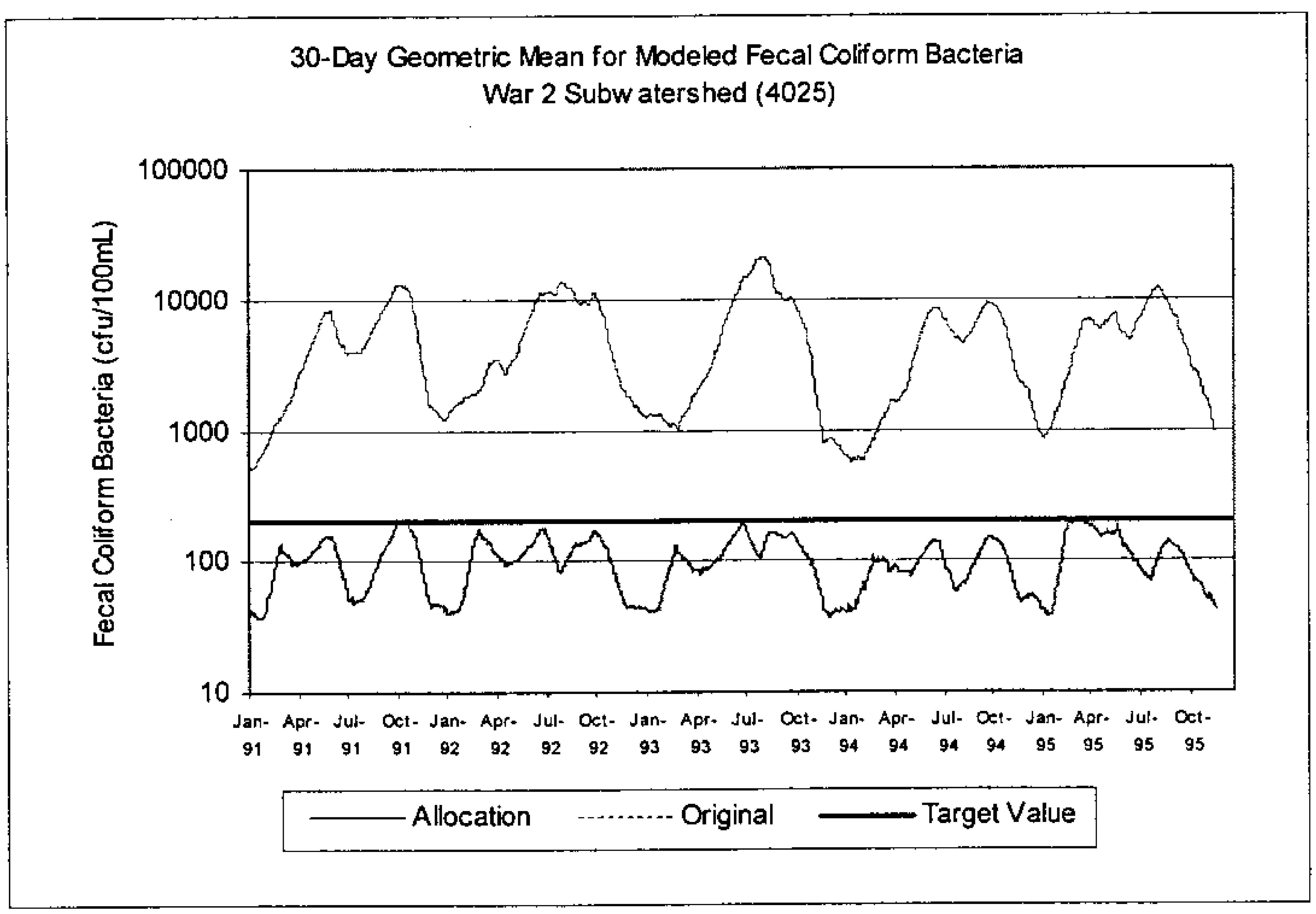


Figure 4. Fecal coliform concentrations under modeled existing and permitted load allocation conditions for War 2 sub-watershed

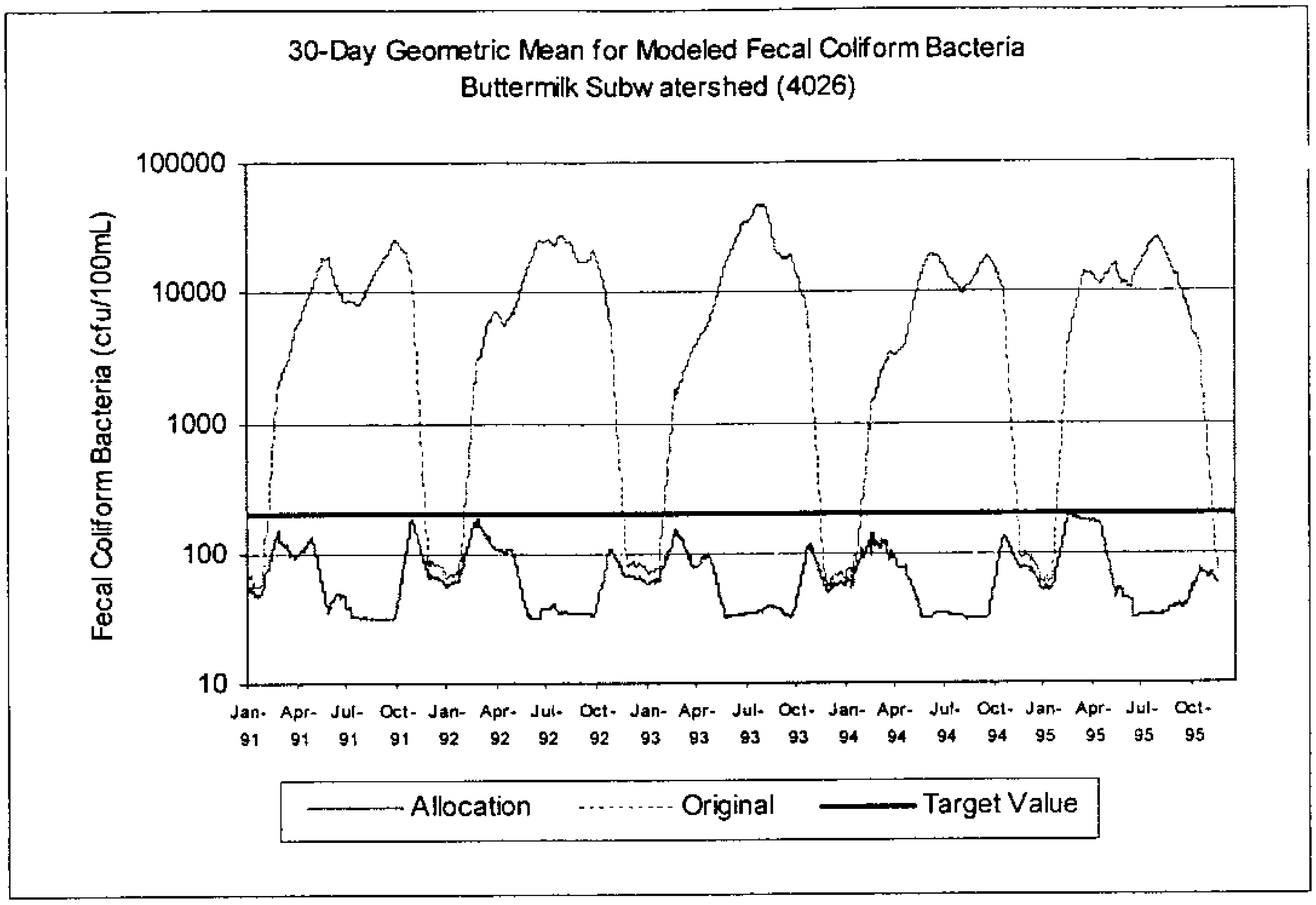


Figure 5. Fecal coliform concentrations under modeled existing and permitted load allocation conditions for Buttermilk sub-watershed

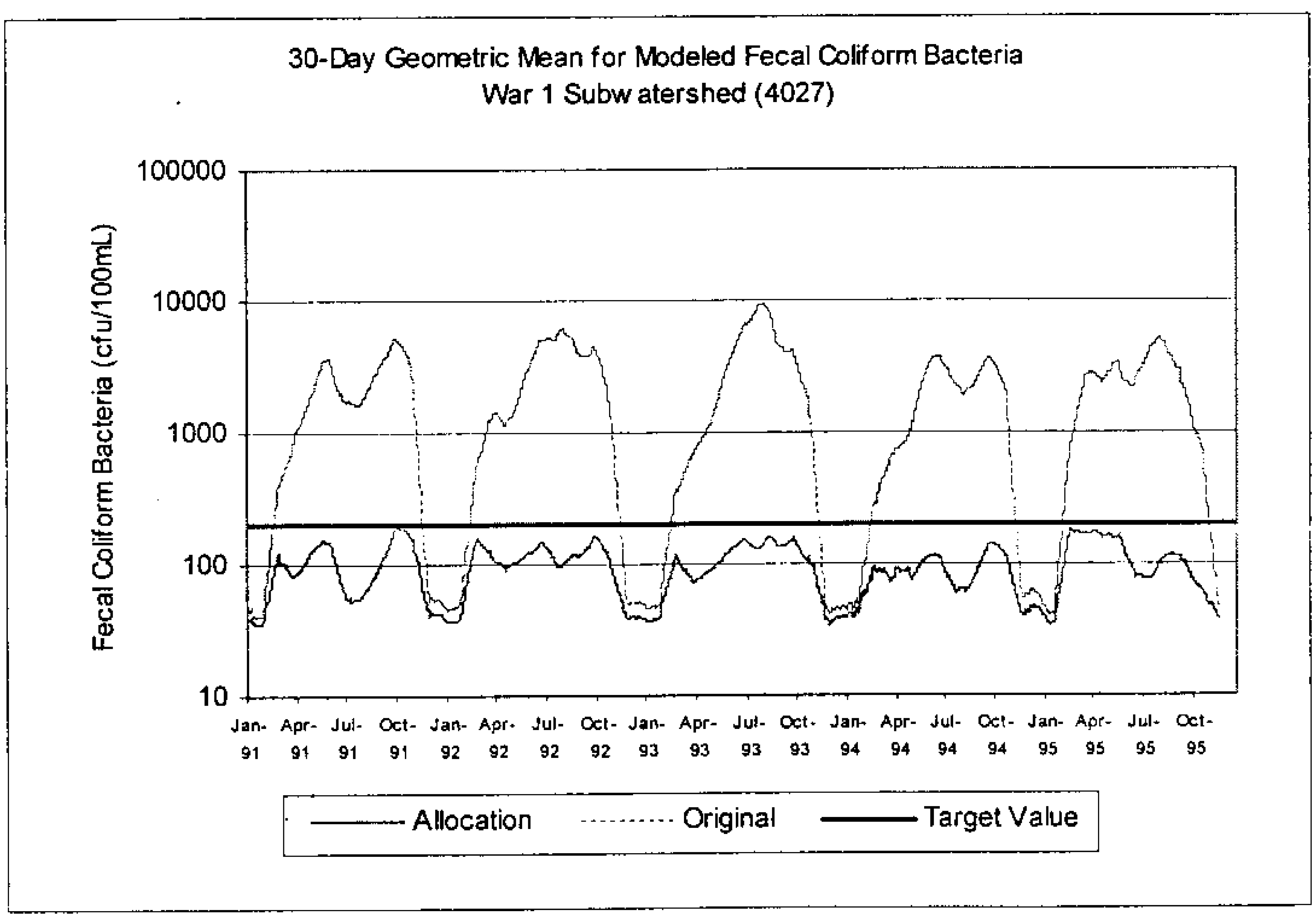


Figure 6. Fecal coliform concentrations under modeled existing and permitted load allocation conditions for War 1 sub-watershed

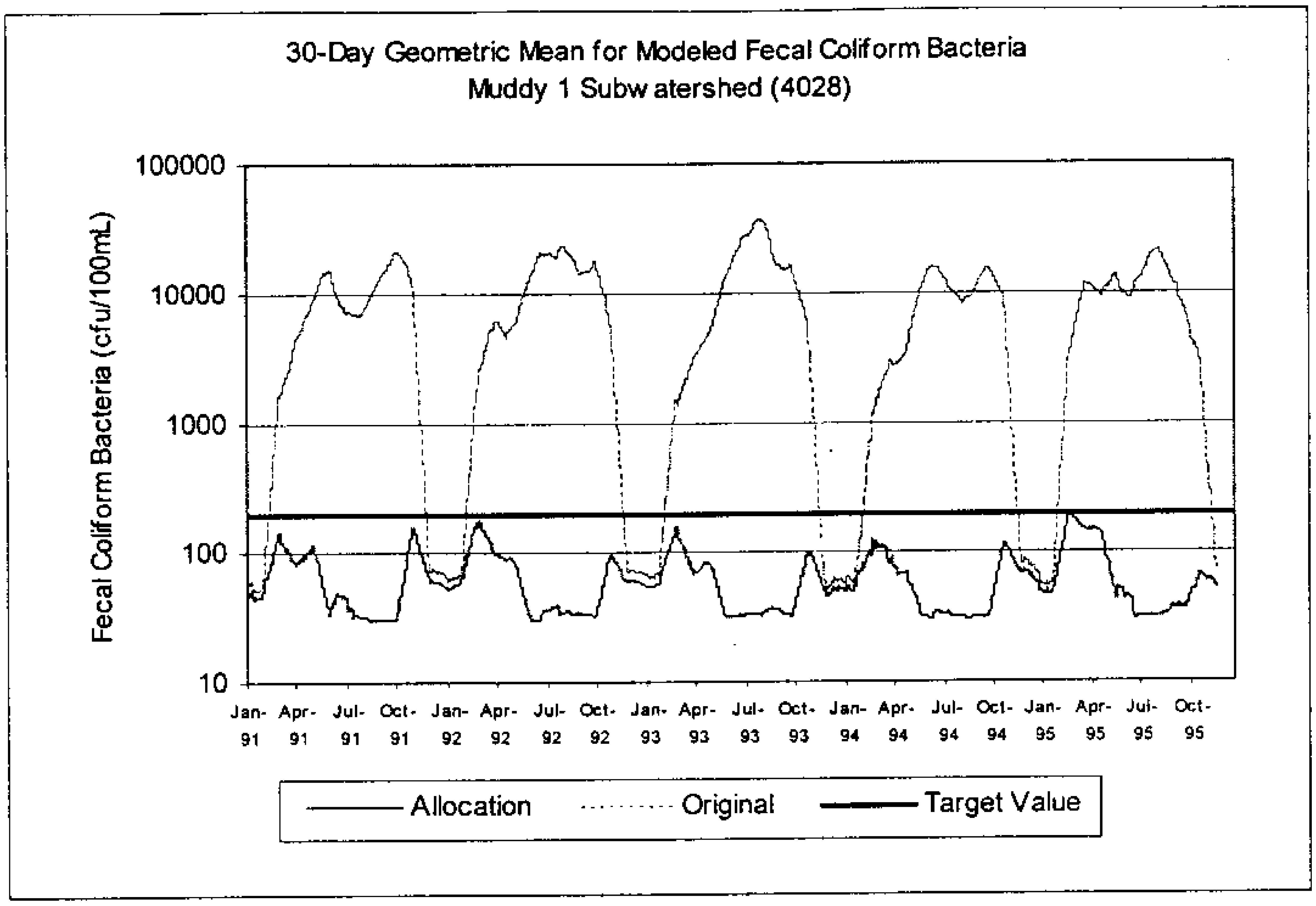


Figure 7. Fecal coliform concentrations under modeled existing and permitted load allocation conditions for Muddy 1 sub-watershed

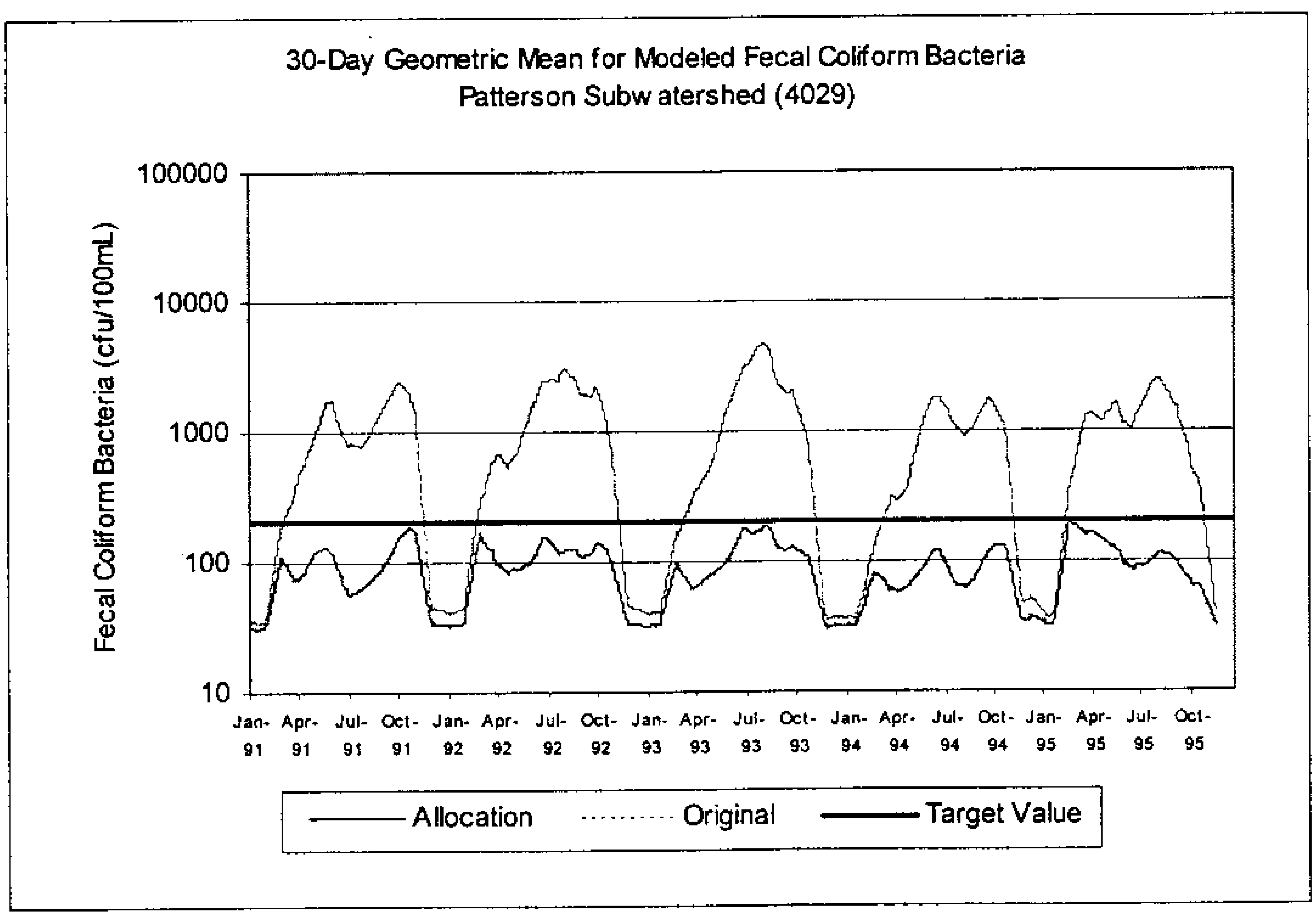


Figure 8. Fecal coliform concentrations under modeled existing and permitted load allocation conditions for Patterson sub-watershed

C.3 Conclusions

From the preceding analysis, one can see that even conservatively allowing for the permitted point source load, the water quality standard for fecal coliform bacteria will be met with 0% exceedances, given an implicit MOS. Furthermore, a 5% explicit MOS is provided with few violations. Therefore, no modifications of the load allocations in the fecal coliform TMDL for Muddy Creek, Virginia, will be required to accommodate the permitted load of the major point source.

C.4 References

Culver, T.B., X. Zhang, T. Naperala, A. Potts, K. Neeley, S. Yu, R. Gregory, C. Martin, R. Bodkin, T. Mizell, D. Lazarus, M. Bennett, C. Wade, and J. Schneider, *Nitrate TMDL Development for Muddy Creek/Dry River, Virginia*, June 2000, University of Virginia, Virginia Department of Environmental Quality, and Virginia Department of Conservation and Recreation.

Muddy Creek TMDL Establishment Workgroup, *Fecal Coliform TMDL Development for Muddy Creek, Virginia*, July 1999.

U.S. Environmental Protection Agency. 1998. *Better Assessment Science Integrating Point and Nonpoint Sources, BASINS, Version 2.0 Users Manual.* Office of Water, Washington, DC. EPA-823-B-98-006. November 1998.